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AN INVESTIGATION OF THE INFLUENCE OF ELECTRICAL FIELDS UPON SPECTRAL LINES

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In the autumn of 1905 the writer began an investigation in the Cavendish Laboratory, Cambridge University, upon the influence which electrical fields producing luminous discharges might have upon the spectral lines comprising the luminosity concomitant with those discharges. The particular points toward which attention was to be directed were whether any variation of wave-length (Doppler effect) occurred when the direction of viewing the discharge was changed from that along the discharge to one at right angles to it; whether the width of the spectral line altered when the part of the luminous column used as a source was changed; whether any polarization of the radiation from the luminous column was produced by the discharge; whether Roentgen rays in their passage through the luminous gas produced any change of wave-length, widening of the lines, or polarization of the light.

Looking at these questions from the experimental view-point, evidence could be adduced favoring either positive or negative results. The extremely accurate work of Michelson, and later of Pérot and Fabry, made it clear that no Doppler effects were to be expected in ordinary end-on discharge tubes. On the other hand, the well-known Feddersen experiment, in which the oscillations of a condenser discharging between two spheres in air at ordinary pressure are

made evident by means of a rotating mirror, leads to the usual explanation that the curving of the images of the spark is due to luminous particles traveling out from the spark terminals. Indeed, Schuster and Hemsalech made an extended study of this curvature for the individual lines composing the discharge when various substances were used for the spark-gap. Their conclusions were that in general luminous metallic particles from the electrodes were driven out along the spark-gap, with various velocities reaching a value as high as 2000 meters per second. These experiments made by Schuster and Hemsalech certainly suggest that a Doppler effect will be found in electrical discharges in air between metallic electrodes. But it will be shown here that another interpretation may be given to their results.

The investigation will be discussed here under the following heads:

1. Doppler effects for discharges in air.
2. Doppler effects in end-on discharge tubes between the electrodes.
3. Change of wave-length, widening of the lines, or polarization of the light due to Roentgen rays.
4. Doppler effects in end-on discharge tubes behind a perforated electrode. (Canal rays.)
5. Polarization of the radiation from the luminous column.
6. Influence of the electrical field upon spectral lines.

Instruments.—At the time when this experiment was started the chief instrument available was an echelon spectroscope by Hilger, kindly loaned to the writer by Professor Liveing. The echelon prism consisted of seventeen plates (eighteen steps of 1 mm each), 7.5 mm each in thickness. The dispersive power was equivalent to that of a grating of 9,600 lines to the millimeter, or sixteen times as great as that of the ordinary grating, and the resolving power to that of a grating of 180,000 lines.

The telescope and collimator lenses had an aperture of 5 cm and a focal length of 40 cm. The telescope carried a plate-holder which could be rotated about a vertical axis so that a considerable part of the spectrum could be brought into focus at one time.

The mounting of the instrument was arranged as in the diagram (Fig. 1). Usually the source of light studied was placed directly in front of the slit *S* of the collimator. The radiations after passing

through the echelon prism E were analyzed by a flint glass prism F, of 60° angle, so that in the focal plane of T there appeared what looked like the ordinary line-spectrum of the source, except that some of the lines might be double and might have a few satellites. These apparently double lines of course were different orders of the same line, their angular distance apart being λ/e, where e was the width of the step. The linear distance between the orders on the photographic plate was approximately 0.2 mm. Except for quite complex sources, there was no difficulty in identifying the lines. This simple method of separating the lines is greatly to be preferred to that of

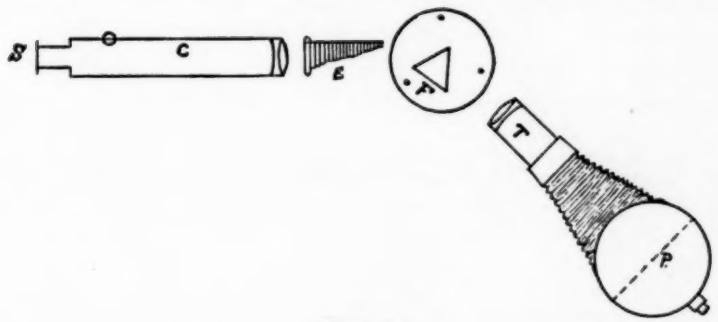


FIG. 1

analyzing the light before it enters the collimator, for in the latter method the lines of the spectrum have to be examined or photographed separately. In this method they all can be photographed at once. The strips of the echelon (1 mm in width), the slit of the collimator and the edge of the prism were made vertical.

In front of the slit of the collimator was a movable diaphragm by means of which the upper or lower half of the slit could be exposed to the source. For example, if the Doppler effect in the canal rays of mercury was to be tested, one-half of the slit was exposed to the canal stream directed at about 10° to the axis of the collimator, then the other half of the slit was exposed to an ordinary mercury-spectrum tube. Fig. 2 shows the appearance of a plate (enlarged two diameters; the fine lines have been lost in the process) when canal rays in helium (*a*) and a helium-spectrum tube (*b*) were sources. If any Doppler effect was present, it would be made evident by a shift of the two halves relatively to one another. There might easily be some doubt

regarding the interpretation to be placed upon this shift. For, confining our attention to one radiation, there would be in general on the plate two maxima corresponding to (say) the 8000 and 8001 orders. If the radiation were shortened in wave-length by about 0.5 tenth-meter, the maximum toward the shorter side of the echelon would move over and take the place of the other maximum, while a new order would follow it and take its place. If the radiation were lengthened, the shift would be in the opposite direction. In both cases the two maxima would look like the original two maxima. Thus, though a variation in wave-length of 0.1 tenth-meter would pro-

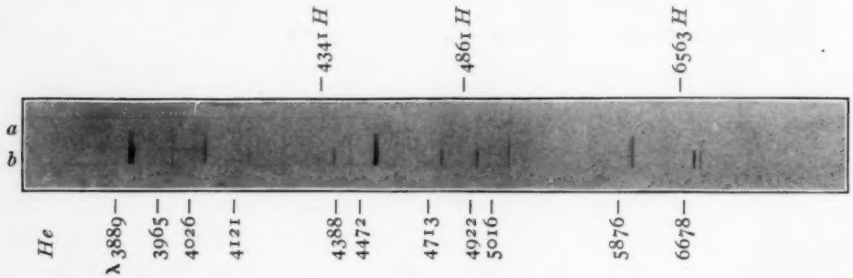


FIG. 2

duce a very marked shift in the lines, one of 0.5 might not cause a noticeable displacement. But shifts as great as 0.2 tenth-meter could be detected and measured by the single prism *F*, the echelon being removed. The method therefore used for determining the order of magnitude and nature of the shift was to remove the echelon and take a photograph of the spectrum through the prism *F*. It is evident that when the echelon is in use the width of the spectral lines used cannot be as great as 0.5 tenth-meter, otherwise the two chief orders would overlap. By width of a line is here meant the wave-length interval between two radiations whose intensities are one-half that of the maximum.

When the echelon and prism were arranged as in Fig. 1, a shift of the lines toward the red end of the spectrum denoted a shortening of those lines.

Adjustment for focus.—The slit and the photographic plate were placed at the foci of their respective objectives by the ordinary method

of parallax. Then through the 60° prism photographs were taken of the upper half of the slit, the right half of the collimator objective being diaphragmed, and of the lower half of the slit with the left half of the lens shadowed. The light source was a mercury, cadmium, or helium discharge tube. The displacements of the two halves of the slit-images were measured for the separate lines, then this process was repeated for a new position of the camera objective, or of the slit or for a new inclination of the photographic plate. At least a dozen plates were taken before a satisfactory adjustment was found. Even then it was not quite possible to bring the upper and lower halves together for all the lines of an extended spectrum. When the echelon was placed in position, it was found that the focus had slightly changed, so that a new position for the camera objective and photographic plate had to be determined.

The echelon prism was adjusted visually. This adjustment was considered satisfactory when the five[1] satellites of the green mercury line were sharp and uniform throughout their length.

An interferometer of the Michelson form (from W. & L. E. Gurley) was also available during these experiments, but of course it could be used only when the light-sources were strong and the radiations simple.

A Rowland concave grating of 10.5 feet radius, 14,438 lines to the inch, 4-inch ruled surface, was also used, but experience proved that for the long exposures required the instrument was affected by temperature-changes and by tremors of its support. The results obtained by this instrument were rejected as unreliable.

1. *Discharges in air.*—As already stated, the Feddersen experiment and the investigation of Schuster and Hemsalech suggest that in electric discharges between metallic terminals in air luminous vapors move along the line of discharge. When the present investigations were begun, the writer did not know of Mohler's paper on "Doppler Effect and Reversal in Spark Spectra."[2] Mohler used Leyden jars of a capacity of 22.5 meters in the secondary circuit of an induction

[1] It is now pretty certain that the large number (twenty) of satellites announced by Lummer and Gehrcke as belonging to the mercury lines were, for the most part, ghosts. The green line λ 5461 has five, or possibly six, satellites.

[2] *Astrophysical Journal*, **15**, 125, 1902.

coil operated by a Wehnelt break. The analyzer was a concave grating of 10 feet radius, 14,400 lines to the inch, 4-inch surface. The most noticeable effect observed by Mohler was that, when the spark from magnesium was going away from the slit, the lines λλ 2795, 2802, 2856 were reversed. With regard to the Doppler effect the only datum given by Mohler is that the aluminium lines λλ 3961, 3944 give an average measured displacement of 0.01 tenth-meter. This shift would be produced by a velocity of 370 meters per second.

The criticism to be made of this result is that the aluminium lines so produced are very broad (probably 2 or 3 tenth-meters)—so broad that it is very doubtful whether a shift of this magnitude could be measured, or if measured whether it might not be due to unsymmetrical broadening.

In considering the most favorable materials for the spark terminals, the writer had chosen an amalgam of mercury and cadmium. These substances give strong, fine lines. Moreover, the velocity of the luminous vapor of mercury, as found by Schuster and Hemsalech, was about 900 meters per second, and of cadmium about 600 meters per second.

Figure 3 shows the first arrangement of the cadmium-mercury and aluminium electrodes. These were held by a hard-rubber plate which could be rotated about an axis passing through the middle of the spark-gap at right angles to the plane of the plate. The line of discharge in general made an angle of 30° with the axis of the collimator. One half of the slit received light directly from the spark, the other half received the light after reflection at the mirrors m_1, m_2 and m_3; the last mirror being a small silvered strip of glass immediately in front of the slit.

If the luminous *Cd-Hg* particles are moving with a velocity v, the difference in wave-length of the two beams through the upper and lower halves of the slit is a $\lambda\frac{2v}{V}\cos 30°$, where V is the velocity of light. If the mercury particles have a velocity of 900 meters per second, the wave-length difference should amount to 0.025 tenth-meters.

Photographing the two halves of the slit simultaneously has the advantage that, if the wave-length of the radiation from the spark

depends upon conditions[1] under which that spark is produced, the simultaneous photographs should eliminate differences in wave-lengths due to those conditions. But this arrangement has a defect. For in using the echelon prism the greatest care must be taken in the alignment of the light beam. Removing the echelon and looking through the objective of the collimator, the electrodes and mirrors may be so adjusted that the object-glass is uniformly illuminated by either source, and thus the alignment is made satisfactory. But a small shift in the light-source, due for example to a movement of the spark along the electrode or to a motion of one of the mirrors, will seriously affect that alignment and may possibly produce a displacement of the two photographic halves of the slit. It would be better then, to allow more freedom in varying conditions. So finally the mirrors were dispensed with entirely. A movable diaphragm allowed either half of the slit to be exposed. The direction of the discharge was changed by rotating the electrodes about the axis at right angles to the spark-gap. Before every set of readings the echelon was removed, and the position of the spark-gap so adjusted that the light beam fell centrally on the objective when either half of the slit was open and for either direction of the discharge. A lens of 5 cm focal length between the electrodes and the slit, and about 5.5 cm from the spark gap, assisted in the alignment and insured light falling upon all parts of the objective of the collimator. The discharge was produced by an induction coil (with a hammer break) capable of giving a 20-cm spark. The spark-gap circuit had in series a small self-induction (0.01 henry). To make sure that the discharge passed in only one direction, a rectifier or electrical valve was included in the spark-gap circuit. The plates were measured by a Zeiss microscope whose micrometer screw was of ½ mm pitch. The distance between two successive orders of a line was taken for various lines, and all other readings were referred to this interval. It happened that tenths of divisions of the micrometer head corresponded nearly to 0.001 tenth-meters. The average error of setting on a good line was 0.002 tenth-meters.

[1] Haschek (*Sitzungsberichte der Kais. der Wiss. in Wien*, 110, 1901) states that the wave-length from a spark depends on the pressure in the spark and also upon the density of the vapor. But later investigations failed to verify his results. See note in *Astrophysical Journal*, **14**, 201, 1901.

Although a great number of plates were taken, only those were measured on which the upper and lower images were nearly equal in intensity and were neither over- nor under-exposed. A photograph in which the upper half of the slit had been exposed to the approaching spark and the lower half to the opposite was combined with one for which the conditions were reversed.

FIG. 3

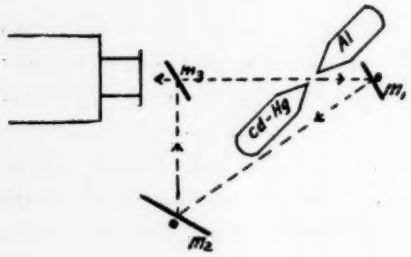
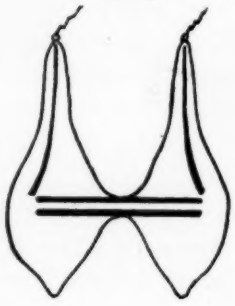


FIG. 4



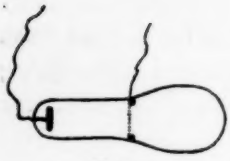


FIG. 5

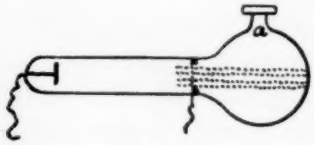


FIG. 6

The mercury and cadmium lines on the plates, making allowance for the width of the slit, which was about 0.02 mm, had a width of between 0.02 and 0.08 tenth-meters. Several of the satellites of the mercury lines appeared on the plates. This gives an indication of their fineness, as does also the fact that interference fringes for a difference of path of 80,000 waves were obtained for the green mercury line.[1]

The following table shows the variations of the readings. A plus sign means that the shift of the upper and lower photographic halves

[1] Nutting, in the *Astrophysical Journal*, **23**, 66, 1906, states that the widths of the lines for sparks in air are never less than 0.5 tenth-meter. This limit is considerably greater than that obtained by the writer.

of the slit was of the same sign as a Doppler effect, and a negative sign that it was opposite to that effect. The readings are in tenth-meters, and are reduced to motion along and at right angles to the discharge.

TABLE I

Line	Plates					Mean
	Nos. 111 and 114	Nos. 112 and 113	Nos. 115 and 116	Nos. 125 and 126	Nos. 127 and 128	
	t.-m.	*t.-m.*	*t.-m.*	*t.-m.*	*t.-m.*	*t.-m.*
Cd λ 4800.....	+0.004	−0.009	+0.005	−0.009	−0.005	−0.002
Cd 4678.....	+0.003	−0.005	.....	−0.010	−0.003	−0.004
Hg 4359.....	+0.004	−0.001	.....	−0.007	+0.004	0.000
Hg 4047.....	.....	.....	.....	−0.002	+0.007	+0.002
Mean.....	.....	.....	.....	.....	.....	−0.001

These data show that for the spark-gap here used, viz., *Cd-Hg* electrodes, 3 mm length of spark-gap, without capacity but with self-induction, there is no motion of the luminous particles as great as 100 meters per second.

When a small capacity was inserted, the lines broadened and were often reversed, so that it was difficult to measure them accurately. The discrepancies were about three times as large as those in the table, and were both positive and negative. Schuster and Hemsalech did not find that the velocity which they measured decreased with the capacity. There was rather more evidence of an increase of velocity with decrease of capacity.

Hence, if we had analyzed our spark by means of a rotating mirror, we should have found that the discharge was curved, just as it is curved when large capacities are joined to the spark-gap. (The feeble illumination of our spark does not readily permit a direct experimental test.) We are therefore led to the conclusion that this curving of the image of the spark is not due to a motion of the luminous particles (for there is no Doppler effect great enough to account for the curving), but to the propagation among those particles of a condition of luminosity.

2. *Discharges in a partial vacuum.*—Discharges in air having failed to give a Doppler effect, motion of the luminous particles was next looked for in vacuum tubes. Here again mercury vapor was chosen on account of the fineness and strength of its lines. The

interferometer and the echelon spectroscope were used to detect the expected change of wave-length.

An end-on tube of the form shown in Fig. 4 was used. The tube connecting the two bulbs was of about 3-mm internal diameter and about 10 cm long. The aluminium electrodes were brought down near the ends of the tube which terminated near the glass walls.

Before sealing off from the pump, exhaustion and sparking were continued until all gases but mercury vapor (as far as could be seen by the spectrum) had been removed. Consequently, at ordinary temperatures the discharge passed with difficulty.

During an experiment the tube rested in an asbestos-covered brass box which could be maintained at a fairly constant temperature up to 250° C. for a considerable time.

Interference fringes for a difference of path of 400,000 waves (this limit was fixed by the shortness of the instrument) were easily found for the green line. These fringes were observed by means of a telescope in the eyepiece of which was a system of cross-hairs. The position of the central fringes could be read to approximately one-tenth of the distance between them. No change could be seen in the fringes when the discharge was reversed. This means that no change of wave-length occurred greater than one part in four million. The velocity of the luminous particles, assuming that it was reversed with the discharge, therefore could not have been greater than 50 meters per second. The results obtained using the echelon prism as analyser were in accord with the interferometer result.

No systematic record of the temperature of the tube was made. Conditions were merely varied from one in which there was a great deal of vapor in the tube to one in which there was very little.

3. *The influence of the passage of Roentgen rays through the luminous gas.*—While the previous part of the investigation was in progress it was thought well to test whether Roentgen rays in their passage through the luminous gas would in any way affect the radiation. The theoretical bearing of this problem is very interesting.

Professor J. J. Thomson represents a cathode ray as a negative corpuscle moving with great velocity and carrying with it lines of force. When this particle is suddenly stopped, a pulse runs out along these lines of electric force. This pulse is the X-ray. It is polarized, its electrical component being in the plane containing

the line of force and the direction of the original motion of the cathode particle. When this pulse is arrested by coming in contact with a new medium, there is generated another radiation the direction of propagation of which is at right angles to the plane just described. These theoretical conclusions have been verified by Barkla[1] in a series of most interesting experiments. We know that this electric pulse or X-ray passing through a gas ionizes it. That is, the electric pulse tears from each of a number of molecules one or more electrons. If the molecule were luminous, this disturbance, amounting to a collision, would affect the phase of the radiation, and would therefore produce a widening of the line. Moreover, if the wave-length depends upon the number of electrons in a molecule, the length of the wave would be changed. Again, this sudden tearing-off of an electron might give rise to an increased radiation in a direction at right angles to that of the pulse. With interference fringes corresponding to a difference of path of 400,000 waves no change of wave-length nor widening of the line was noticeable.

The polarization was looked for with a Nicol prism and sensitive Savart plate, but none was found.

This experiment is of interest in connection with the optical phenomenon of absorption. Ether pulses or X-rays passing through a gas are absorbed to a very small extent, but produce marked ionization. Ether waves (of the order of light-waves) may experience considerable absorption, as is the case for ultra-violet light in iodine vapor, but produce no ionization;[2] the present experiment shows that an increase in the ionization of a gas (for the gas here studied) does not affect its absorption or emission. Apparently absorption of energy is always necessary to produce ionization, but ionization need not accompany absorption. It requires the absorption of a special kind or form of energy, for example that of electric pulses, of short-period light-waves,[3] or of waves specially suited to the gas,[4] to produce ionization.

[1] *Phil. Trans.*, A, **204**, 467–479, 1905.

[2] Henry (*Proc. Camb. Phil. Soc.* **9**, 1897) found that there was no increase in conductivity in iodine vapor when illuminated by ultra-violet light.

[3] P. Lenard (*Ann. der Phys.* (4) **1**, 486; **3**, 289, 1900) found that easily absorbed radiation from an electric spark produced ionization.

[4] Sodium vapor is rendered specially conducting by yellow light, potassium by blue. Elster and Geitel, *Wied. Ann.*, **52**, 433, 1894.

4. *Doppler effects in end-on discharge tubes behind a perforated electrode.*—As discharges through mercury vapor in end-on tubes had produced no Doppler effect, attention was turned to other forms of tubes and other gases, when Stark announced the phenomenon here looked for—the Doppler effect in the canal rays of hydrogen. This gas had not been used at the outset of the present experiments, because the principal lines of hydrogen are so broad as not to lend themselves readily to analysis by the echelon prism. Moreover, it was not expected that an effect would be discovered large enough to be detected by other means at the writer's disposal. But the first test showed that the effect was easily seen when the prism F was used as an analyzer. One half of the slit was illuminated by light from an ordinary hydrogen spectrum tube, the other by the canal rays in hydrogen. An observer at the telescope could clearly see the lines from the canal rays shift from one side to the other of the ordinary hydrogen lines as the canal stream was directed toward or away from the slit. The photographic plates showed that the shift was about 5 tenth-meters, corresponding to a velocity of the luminous particles of about 3×10^7 cm per second.

An attempt was made to obtain the effect for mercury vapor. The tubes used had the form shown in Fig. 5. The distance between the electrodes was about 10 cm, the diameter of the tube about 3 cm. The discharge was produced by an induction coil, the potential ranging from 1,000 to 30,000 volts, though for any one exposure the potential was kept as nearly constant as possible by regulating the temperature of the tube.

The echelon was put in its place, and photographs of the two halves of the slit were taken, one half being illuminated by the ordinary mercury discharge tube, the other half by the canal stream. Great care was taken to have the objective of the collimator full of light. The tube was inclined at an angle of about 20° to the axis of the collimator, and so placed that no light but that from the canal stream passed through the spectroscope.

The first tube used to test the Doppler effect in the mercury canal stream was that which showed that effect for hydrogen, for there were present in the canal stream not only the hydrogen but also the mercury lines. Using the interferometer as analyzer, with fringes

corresponding to a difference of path of 120,000 waves of the green line λ 5461, no variation in wave-length was seen when the canal tube was rotated through 120°. The visibility of the fringes rapidly decreased for a greater path-difference. With interference for this difference of path a change of wave-length of one part in six hundred thousand could be detected. That is to say, the Doppler effect for the mercury particles in that tube could not have been as great as 0.01 tenth-meters, or, considering that the direction had been altered from $+60°$ to $-60°$, the velocity of the particle could not have been greater than 300 meters per second. The echelon results placed the limit rather lower than this.

The discharges that were used with this tube had been so heavy that the anode melted and became distorted, rendering the tube useless. Another tube, similar in form and dimensions, was prepared. When this tube was sealed off from the pump (pressure about 0.06 mm of mercury), both hydrogen and mercury lines were present, but the former disappeared after a few plates were taken. The discharges used were heavy, the potential being about 4000 volts. The time required for an exposure (slit-width being 0.02 mm, Lumière "Sigma" plates being used) varied from 8 to 15 minutes. With this tube eight plates were taken, two of which showed a shift of about one-fifth of the interval between the two maxima. But the interpretation placed upon this at the time was that the shift was not one-fifth but six-fifths of that interval. The reason for this interpretation was that there were irregularities in the measurements which could not be accounted for if the smaller fraction were correct, but which seemed reasonable if the larger one were chosen. Moreover, the larger value gave a velocity of the mercury particles of 2.5×10^4 meters per second, which value was consistent with that found for the hydrogen particles. It was intended to find the order of the shift by the single prism, but unfortunately before this could be done the tube had hardened considerably, and the conditions had so changed that the plates now showed no certain shift. A test with the interferometer gave fringes (for the green line λ 5461) for a difference of path of 120,000 waves. These fringes were not changed by turning the tube through 120°. Consequently the velocity of the luminous

particles (in the later history of this tube) could not have been greater than 300 meters per second.

Three other tubes were made, one of which contained hydrogen and mercury vapor, the other two containing only mercury vapor as far as any spectroscopic test could determine. The last two tubes required heating before the discharge took place; even then the potential was apt to run high, up to 60,000 volts or more. A number of plates were taken with the canal streams in these tubes as sources, but no shift of the mercury line was found.

At the time these experiments were performed it was thought that the shift obtained in two of the plates was real and that the nterpretation placed upon it was correct. In a preliminary note published in the *Proceedings of the Royal Society*, June 1906, it was stated that the Doppler effect for mercury had been found, but a re-inspection of all the data, and new data obtained by using the canal stream in helium as a source, leads the writer to suspect that the shift obtained on the two plates was accidental. If it was due to a Doppler effect, then that effect is dependent upon conditions which are not evident. Neither increasing the potential or the current nor freeing the tube from gases other than mercury vapor produces the effect.

Since the preliminary note was written the writer has made other attempts to obtain the Doppler effect in mercury vapor, but without success.

Helium next suggested itself as a substance with which to work. In contrast to mercury, it has a low atomic weight. Moreover, it has an increasing spectrum consisting of six series, according to Runge and Paschen, two principal series each with two secondary series. If the Doppler effect differed for lines of different series, certainly that difference should be made evident in the canal rays of helium.

The gas obtained from Tyrer & Co., London, proved to be quite pure. The photographs taken through the prism F with a spectrum tube filled with this gas as a source gave all the lines from λ 7281.8 to λ 3819.8 without a trace of impurity[1]. The canal ray tube was the one which had been used for obtaining the rays in hydrogen.

Table II, column 3, gives the relative intensities of the lines as

[1] After long usage, however hydrogen lines made their appearance.

TABLE II

	λ	Relative Intensity in Plücker Tube	Relative Intensity Canal Discharge	Shift per 1000 Volts
2d Sub *B*	7281.80	1	0.00	
2d Sub *A*	7060.00	1	0.00	
	7065.50	4	0.00	
1st Sub *B*	6678.40	10	0.04	
1st Sub *A*	5876.21	2	0.27	
	5875.87	20	0.27	+0.004 t.-m.
2d Sub *B*	5047.80	2	0.00	
2d Prin. *B*	5015.70	10	0.27	+0.004
1st Sub *B*	4922.00	6	0.14	
2d Sub *A*	4713.48	1	0.11	
	4713.25	8	0.11	+0.004
1st Sub *A*	4471.86	2	0.33	
	4471.65	20	0.33	+0.004
2d Sub *B*	4437.70	2	0.00	
1st Sub *B*	4388.10	8	0.26	+0.005
2d Sub *B*	4169.10	1	0.00	
1st Sub *B*	4143.90	2	0.13	
2d Sub *A*	4121.00	6	0.03	
1st Sub *A*	4026.51	1	0.30	
	4026.34	10	0.30	+0.006
2d Prin. *B*	3964.87	6	0.10	
1st Prin. *A*	3889.00	40	0.17	+0.004
2d Sub *A*	3867.60	1	0.00	
1st Sub *A*	3819.80	2	0.25	

they appeared on the plate (Wratten & Wainwright "pan-chromatic" plates, Plücker tubes as source) with the classification as given by Runge and Paschen. Here the first and second principal series are denoted by *A* and *B* respectively. The fourth column gives the intensity, estimated from seven different plates, of a line in the canal spectrum compared with that of the same line in the ordinary Plücker tube. It is evident from an inspection of this column that the lines of the first sub-series *A* are relatively stronger in the canal ray spectrum than they are in the Plücker tube spectrum. The two principal series are next in order, while the lines of the two second subordinate series are seldom visible in the canal stream. The relative intensities for the various lines, comparing canal rays with Plücker tube, are: first sub-series *A*, 0.30; principal series *A* and *B*, 0.18; first sub-series *B*, 0.13; second sub-series *A*, 0.05; second sub-series *B*, 0.00.[1]

[1] When the direction of the current was changed so that cathode rays in place of the canal stream appeared behind the perforated plate the spectrum changed from yellow to green-blue. The intensities of the lines were completely changed. The red and yellow lines disappeared while λ 5016 came out strong.

The discharge was obtained from an induction coil. A spark-gap, whose terminals were brass spheres one inch in diameter in multiple with the canal ray tube, allowed one to estimate the potential difference between the electrodes.

Two plates were taken with the flint glass prism as analyzer. The dispersion of this prism gave a variation of from 25 to 35 tenth-meters per millimeter. These plates showed that there was no Doppler effect in the helium canal stream as great as 0.1 tenth-meter.

A number of plates were taken with the echelon in place, and of these six were measured. The tube was refilled with helium after plate No. 218 was taken. Table III gives the estimated potential, the mean shift in the direction of the Doppler effect for all the lines on that plate, and the times of exposure for the Plücker and canal ray tubes.

TABLE III

Plate	Potential in Volts	Mean Shift	Time in Minutes
217	9,000	+0.008 t.-m.	6 and 100
218	16,000	+0.006	5 and 150
219	3,000	+0.008	5 and 100
220	7,000	+0.025	6 and 165
222	22,000	+0.003	7 and 150
223	36,000	+0.022	8 and 165

It will be noticed that, assuming these shifts are due to real Doppler effects, there is no apparent connection between the shifts and the potentials. But if it be assumed that the shift is proportional to the square root of the potential, then column 5 of Table II follows. Other lines than those given in the table were measured, but on account of their faintness or fuzziness through poor focus they are not included.

These data indicate that the Doppler effect for the lines in the canal stream of hydrogen is of the order of 4 tenth-meters for a potential of 1,000 volts. Assuming the velocity to vary inversely as the square root of the molecular weight, we deduce from this displacement for the lines in the canal rays of helium a Doppler effect about six hundred times as great as that which is given by this experiment.

It therefore appears from these investigations that the luminous hydrogen particles in the canal stream in that gas have a velocity of

the same order as that deduced by Wien from the electric and magnetic deflections. But the luminous particles of helium and generally those of mercury have velocities very small compared with that which we should expect from the electric experiments.

It follows that the canal particles in helium and mercury either do not have nearly as great a velocity as they are generally supposed to have, or that the *luminous particles* do not take part in the large velocity. In the latter case non-luminous particles must be streaming through the gas with great velocity, producing luminosity in other particles, probably by bombardment, and giving to those particles a fraction of their own velocity. The mass of the non-luminous particle would have to bear to that of the luminous the ratio of the mass of the electron to that of the hydrogen atom to explain the results in the case of helium. But we have no experimental evidence that the canal rays in helium and mercury have a velocity greater than that here determined optically. Experiments are now under way to measure the Doppler effect in the canal stream of other gases, and also to test the velocity by means of the magnetic and electrostatic deflections.

5. *A test of the polarization of the radiation from the canal rays.*—A glass tube (*a*) was sealed on to a canal ray bulb at right angles to the direction of the rays as in Fig. 6. On this tube was sealed a piece of optical glass as free as possible from strain. Outside of this plate of glass was arranged a series of diaphragms which prevented light from the sides of the tube *a* from passing through the analyzer, which was a very sensitive combination of Savart plate and Nicol prism. The canal stream was that in hydrogen and showed the Doppler effect for the lines of that gas. No polarization of the radiation from the canal rays could be detected.

Voigt,[1] from theoretical considerations, predicts a polarization of the light emitted from luminous particles in an electrical field. This polarization should persist during the subsequent motion of the particle in the canal rays.

Stark,[2] in a paper published during the present investigation, claims to have found this polarization in the light emitted by the

[1] *Ann. der Phys.*, (4) **4**, 197, 1901.

[2] *Deutsch. Phys. Gesell. Verh.*, **8**, 6, 1906.

canal rays. He used a Nicol prism as detector, but gives no details regarding precautions taken to eliminate the effects of reflections from the glass surfaces or of transmission through the strained glass forming the walls of the tube.

Although no accurate quantitative measurements were taken of the sensitiveness of the Savart plate and Nicol prism here used, observations on the polarization of the light from the sky near the Sun and on the light reflected at small angles of incidence from black glass surfaces, taken with a knowledge of the sensitiveness of other Savart plates, showed that the detector here used would show a partial polarization of 0.5 per cent. of the total light. Incandescent lamps and electric discharges in all the tubes used and in all parts of the tubes showed strong polarization when viewed through this analyzer. In other words, this analyzer must have been forty or fifty times as sensitive as the Nicol prism used by Stark. But the canal stream in our case showed no polarization. The writer therefore feels that the effect has not been observed, and that the various theories which have been constructed upon it as an observed phenomenon must be re-examined.

6. *The influence of the electrical field upon spectral lines.*—The theoretical deductions regarding the electrical analogue of the Zeeman effect do not lead us to expect that such an effect may be observed. Voigt (*loc. cit.*), for example, concludes that when a luminous vapor in an electrical field of 300 volts per cm is viewed at right angles to the lines of force, the spectral lines will be widened by one two-thousandth part of the distance between the D lines, or by 0.0003 tenth-meter—a quantity which is outside the limit of observation.

From another point of view, however, we may expect an effect. According to Larmor,[1] the motion of a source through the ether may affect the intrinsic free period of the radiant vibrations, the amount depending on the square of the ratio of the translatory velocity to the velocity of radiation. In all ordinary cases this effect would be negligible, but when the velocity of translation approaches that of the canal rays in hydrogen (5×10^5 meters per second), the square of the ratio would give a wave-length change of the order of 0.015 tenth-meter—a quantity which may readily be observed.

The light produced by the electrical discharge in uniform tubes

[1] *Aether and Matter*, p. 46.

3 or 4 cm in diameter was examined perpendicularly to the direction of discharge at various points between the electrodes and also behind the perforated cathode. Thus the electrical field varied from zero, behind the electrodes, to its highest value (about 500 volts per cm) near the cathode. These tubes gave the Doppler effect for the hydrogen lines, but not for those of mercury. About thirty different plates were taken, the echelon prism being the analyzer, the times of exposure varying from 30 minutes to 3 hours. A comparison hydrogen and mercury tube was used.

The data may be gathered together as follows. The hydrogen lines $H\beta$, $H\gamma$, $H\delta$, have widths in the cathode layer, the canal stream, and the positive column of 0.5, 0.4, 0.12 tenth-meter. They are not shifted in any of these cases more than 0.1 tenth-meter. This is an upper limit determined by the use of the single prism *F*. The amount of shift, if any (on account of the width of the hydrogen lines), could not be measured by means of the echelon prism. The lines of the second hydrogen spectrum were not broadened, but appeared to be shifted both in the cathode layer and in the canal rays by 0.01 tenth-meter toward the blue. The lines of the mercury spectrum λλ 5461, 4359, 4047 were not shifted; they might have been slightly broadened. It should be noted that the lines of the second hydrogen spectrum were very faint in the canal stream, so that only the strongest lines appeared on the plate, viz.: λλ 4642 (?), 4639 (?);[1] 4586, 4581, 4574, 4503, 4223, 4213, 4205, 4176.

Attempts were made to photograph the spectrum of helium using the luminous layer covering the cathode as source, but all such attempts failed owing to the very heavy discharge of the metal (aluminium) of the cathode on the tube. The canal rays showed no broadening of the lines. But the velocity of the luminous particle in the canal stream of helium as found by the writer is very small, so that no broadening was to be expected on account of the motion of the luminous mass centers.

Since the broadening of the principal hydrogen lines is found

[1] The lines λλ 4642, 4639 appeared in the spectra of the hydrogen comparison tubes loaned by Professor Liveing and prepared by him with the greatest care; also in the tubes prepared by the writer. If they are oxygen lines, they are the only lines of that element in the spectra used.

behind the cathode where the electric field is very small, that result cannot be attributed to the electrical analogue of the Zeeman effect, unless the change of period persists after the particles escape from the influence of the electrical field in front of the cathode.

Nor does it fall in completely with the prediction made by Larmor, whose theory requires a shift and only a small broadening.

Nor does the theory recently advanced by Professor Thomson[1] account for the effect. That theory accounts for the widening by considering the influence which vibrating electrified corpuscles have upon one another. The widening so obtained is proportional to or increases with the density of the synchronously vibrating corpuscles. But the density of the luminous particles in the canal rays cannot be nearly as great as it is in the ordinary discharge tubes. Consequently, on that theory the lines in the latter case should be the wider. This is contrary to fact.

We may, however, account for the widening here obtained in the following way. The gas in the neighborhood of the cathode is in part the source of the cathode rays. Let us consider, then, an atom with a negative corpuscle vibrating about it, and suppose that this atom ejected a negative corpuscle with great velocity; there would be a new differential motion of the atom and its satellite. In some cases this new relative motion would be tangential to the satellite's orbit. In consequence, the major axis of the orbit would in some cases be increased and in other cases decreased. If a represents the semi-major axis of the orbit, v the tangential velocity, and μ a constant, then $\delta a = \frac{2a^2}{\mu} v \delta v$, where δa and δv are the variations in major axis and tangential velocity. From $T = 2\pi\sqrt{\frac{a^3}{\mu}}$ the relative change in period

$$\frac{dT}{T} = \frac{3a}{\mu} v \cdot \delta v .$$

$$= \frac{3}{4} \frac{T^2}{\pi a^2} v \cdot \delta v .$$

[1] J. J. Thomson, "A Theory of the Widening of the Lines in Spectra," *Proc. Camb. Phil. Soc.*, **13**, 318, 1906.

Substituting the approximate values of T, a, and v, 10^{-15}, 10^{-8}, and 10^{8}, we find that

$$\frac{\delta T}{T} = \pm 10^{-6} \delta v .$$

Since the value of $\frac{\delta T}{T}$ found in the case of the hydrogen lines is of the order of 10^{-4}, we find that $\delta v = 100$ cm. That is to say, if the explosion which takes place when the negative electron is ejected as a cathode corpuscle is sufficient to cause a relative tangential velocity of the nucleus and electron vibrating about it as great as 100 cm per second, the radiation emitted by a group of particles would be rendered less homogeneous to the extent here found. The atoms which have thrown off a negative corpuscle are also those which will be set in motion by the electric field, so that, if luminous, they will exhibit the Doppler effect. On the contrary, if they do not show this effect, they should not on this theory show broadening. The lines in the canal rays of mercury and helium fall in with this test.

In review of the topics treated in this paper, it may be noted that for discharges in air, for the luminous column between the electrodes of end-on discharge tubes, or for the canal rays, the only certain effect obtained has been a Doppler effect and widening of the lines in the canal rays in hydrogen, while for the influence of the electrical field upon spectral lines the only effect has been found to be a widening of the hydrogen lines. It looks as though these phenomena were connected in the manner indicated in this paper. The other results are all negative.

Roentgen rays in their passage through a luminous gas do not affect the radiations in any (as yet) measurable way, nor does a strong electric field impose upon luminous particles any measurable polarization.

These experiments indicate that hydrogen molecules easily acquire a positive charge (lose a negative electron), while the molecules of helium acquire this charge with difficulty. Does not this lead us to favor the view that the alpha particles given out by radioactive substances are molecules of hydrogen rather than of helium, as held by Rutherford? The radioactive phenomena, however, all favor helium.

The writer's thanks are due to Professor Liveing for the loan of apparatus, and to Professor Thomson for the facilities accorded to him. In general, he wishes here to record his tribute to the admirable spirit of comradeship in research which is found in Cambridge, and especially in the Cavendish Laboratory.

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ON THE RADIATION OF CANAL RAYS IN HYDROGEN[1]

By J. STARK

PART I. CARRIERS OF LINE SPECTRA

§ 1. *Introductory.*—As the Zeeman effect indicates both by its magnitude and by its sign, the *centers* of emission for line-spectra are the negative electrons. These form one part of a distinct system of material or electrical centers; and it is this system which we propose to call the "carrier" (*Träger*) of the line spectrum.

In a gas rendered luminous by electrical means, there are, besides neutral atoms, positive atoms—i. e., atoms which, during the process of ionization, have lost one or more negative electrons. It is in these positive atoms (*Atomionen*) that one may expect to find the carriers[2] of the line spectra.

A glow-discharge (*Glimmstrom*) was established in the open air between two electrodes placed in the same vertical line, the anode above, the cathode below. Into the middle of the discharge was introduced a bead of a lithium salt, when it was observed that the red color of the lithium traveled downward toward the cathode, in spite of the convection currents in the gas tending to drive it upward. This result[3] may be explained in various ways upon the assumption that the positive lithium ions are transported by the current toward the cathode. First, one may suppose that the lithium ion is not merely the carrier of the positive charge, but is at the same time the carrier of the line spectrum. Or, secondly, it might be that the light is emitted by the neutral lithium atoms which are formed by the reunion of positive ions and negative electrons at points between the bead of salt and the cathode. In view of the experiments described in this paper, the first explanation appears to be the correct one.

Imagine an electric arc established between mercury electrodes in a vacuum tube to which has been fused a condensing chamber. A

[1] Translated from advanced proofs of an article to appear in the *Annalen der Physik*, communicated by the author.

[2] J. Stark, *Die Elektrizität in Gasen*, p. 447, 1902.

[3] E. Riecke and J. Stark, *Physikalische Zeitschrift*, **5**, 357, 1904,

jet of luminous mercury vapor will then flow into the condensing chamber from the path of the electric current. If now an electric field be passed through this vapor, ending upon a secondary electrode, then, before this field of force is made, the jet of vapor above the cathode yields the line spectrum of mercury; but as soon as the field is established the line spectrum of mercury disappears from the region above the cathode. This result[1] can also be explained in different ways. First, it is possible that the positive mercury ions are the carriers of the line spectrum; so that, when these ions are dragged out of any region to the cathode, the line spectrum goes with them. Or, secondly, it may be that the line spectrum is emitted by the neutral atoms which are excited by collision with negative electrons; the electric field drives these out of the stream of vapor to the cathode; and therefore in the region above the cathode the previously observed emission disappears. According to the results presented in this paper, it is the first of these explanations which is the correct one.

In order to test these hypotheses concerning the carriers of line spectra, one might proceed as follows.[2] According to the researches of W. Wien, canal rays are always partly composed of positive ions moving with high velocities. If, now, they are at the same time emitting spectral lines, the positions of these lines must change, according to Doppler's principle, when the direction along which they are observed changes in reference to the direction of translation in the canal rays. This phenomenon is the subject of the present paper. Preliminary reports[3] on my earlier observations have already been published. In the meantime I have extended and improved upon these; but unfortunately my work has been interrupted by change of residence from Göttingen to Hannover, and it has been impossible for me to substitute, for the tentative results in Parts II and III, exact quantitative measurements. Nevertheless, I now publish this account, in the hope that someone more favorably situated than I will take up these experiments and carry them through.

§ 2. *Method of the experiment.*—The laboratory had at its dis-

[1] J. Stark, *Annalen der Physik*, **14**, 520, 1904.

[2] J. Stark, *Die Elektrizität in Gasen*, p. 457, 1902.

[3] J. Stark, *Physikalische Zeitschrift*, **6**, 892, 1905.

posal four high-tension batteries and one high-tension dynamo; these could be joined up in series so as to yield anywhere from 1,300 to 9,000 volts. When still higher voltages were needed, say from 10,000 to 60,000 volts, a large induction coil with a mercury turbine interrupter was used. With the arrangement of electrodes and with the low pressures which here had to be employed, the negative glow always extended up to the anode. Therefore the cathode-drop (defined as the potential difference between the cathode and the negative glow) is always equal to the voltage between the electrodes; these quantities were measured by means of Braun electrometers, reading from 0 to 3,000 and from 0 to 10,000 volts. This was the mode of working in all cases in which a constant and direct voltage was used. During the entire time of exposure the cathode-drop was maintained to within 15 per cent. of a constant value. If at any time the cathode-drop decreased by more than 15 per cent., the circuit was opened and the tube pumped out until the desired higher value was obtained. If, on the other hand, the vacuum became too high in consequence of the electric discharge, some additional gas was admitted until the cathode-drop again assumed its normal value. The strength of the current was measured by a Deprez ammeter.

The vacuum tubes employed were cylindrical in shape and from 3 to 6 cm in diameter. The cathode was arranged as follows (see Fig. 2). A strip of sheet aluminium, 1 or 2 cm wide, was bent into a cylinder which would just fit into the vacuum tube. Across one end of this cylinder was riveted a circular aluminium disk which was perforated as densely as possible with holes of $\frac{1}{2}$ to 1 mm in diameter. At the other end of the cylinder a platinum wire was attached, as shown in Fig. 2, and then passed through the side of the tube, where it served as one electrode. For anode was used an aluminium disk completely filling the cross-section of the tube. It was not permissible to make the anode small or to place it in a side tube; for if the cathode rays, instead of falling upon the metallic anode, struck the end of the tube, the glass became so hot that the atmospheric pressure was sufficient to crush it. With heavier currents, especially in case the induction coil was used, the aluminium anode, like the anti-cathode in Röntgen bulbs,

was so highly heated that it disintegrated (*zerstäubte*) faster than the cathode.

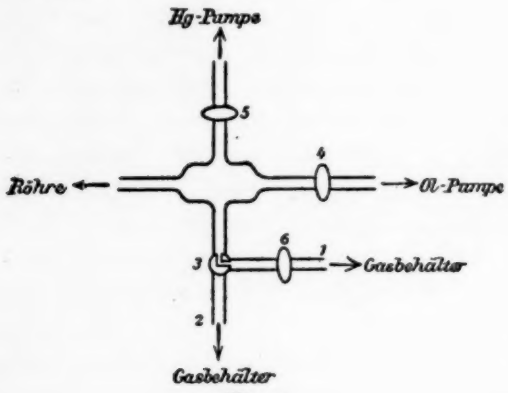


Fig. 1

The distance between anode and cathode was always chosen so large that the Crookes dark space did not reach the anode; for if this were not the case, then the current would cease altogether or the discharge become irregular. Accordingly this distance was always greater than 10 cm and generally amounted to 25 cm. In the observations on the Doppler effect with mercury lines it reached 40 cm.

That portion of the vacuum tube which lay behind the cathode and into which the canal rays passed varied in length, according to circumstances, between 4 and 20 cm.

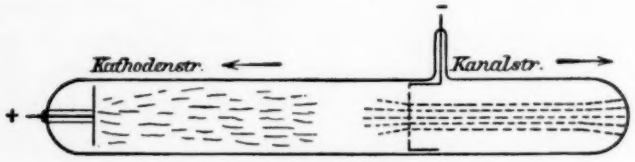


Fig. 2

As is well known, the cathode-drop increases as the gas-pressure diminishes, and simultaneously the length of the Crookes dark space increases; this length may therefore serve as a rough measure of the cathode-drop. This method was employed in the case of the induction coil, since it here became impracticable to use the electrometer; that is, the current was interrupted as soon as the length of the dark space fell below a certain definite limit; then gas was pumped out until on again closing the circuit the dark space assumed a sufficient length.

The exhaustion of the tubes was accomplished by means of two air pumps of the oil type, one yielding 200 cc, the other 400 cc per stroke. The pumps were electrically driven, were carefully kept dry, and so were capable of producing in a short time a vacuum of 0.01 mm. In some experiments as, for instance, that with mercury, even lower pressures were desirable in order to obtain a high value for the cathode-drop. For this purpose a mercury pump was used in conjunction with the larger oil pump. Fig. 1 shows how the two pumps, the gas reservoir, and the tube were connected. At first, cock No. 4 was open, cock No. 5 closed, and the tube exhausted to the limit of the oil-pump; then No. 4 was closed, No. 5 opened, and the mercury-pump set into operation.

The method of introducing the gas will also be seen from Fig. 1. No. 3 was a three-way stopcock, one opening of which was closed with wax, so that the remaining opening formed an elbow. If a large amount of gas was to be admitted, the reservoir was attached to opening No. 1, and cock 3 was set so as to be closed against 1 and 2; then 6 was opened so that the portion of the tube lying between 3 and 6 would fill with gas; next cock 6 was closed and cock 3 set so as to admit to the tube the portion of gas just entrapped. If, however, it was desired to admit only a small quantity of gas, then the reservoir was attached to the opening marked 2; cock 3 was so set as to be closed to the tube and to cock 6, while remaining open to 2. The elbow in the cock would now fill with gas; and, on turning cock 3 through 90°, this elbow would empty its charge of gas into the tube, while remaining closed toward 2 and 6.

The hydrogen for these experiments was sometimes taken from a cylinder of the commercial gas, but generally it was prepared from sulphuric acid and chemically pure zinc. Before admission to the vacuum tube it was passed through two tubes of phosphorus pentoxide, the first 30 cm and the second 25 cm long.

In determining the Doppler effect in canal rays the purity of the gas is a matter of great importance; for upon this depends not only the intensity of the radiation of the canal rays themselves, but also the straightness of their path (§ 9). It does not suffice merely to fill the tube with pure gas; first of all, one must remove the gas which the electric discharge drives out of the electrodes and out of

the glass walls of the tube. The color of the canal rays in hydrogen is a sensitive means for judging of the purity of the gas. When pure, the color is a beautiful red, and as impurities increase the color deviates proportionately from red. At the beginning a new tube will develop so much foreign gas that, after the hydrogen is admitted and the electric current started, the canal rays immediately change color. In these experiments each new tube was purified as follows before any spectrograms were taken. First of all, a strong current was sent through the tube for half an hour, the oil pump being in continuous operation during the entire time. Then hydrogen was admitted until a pressure of 10 mm was attained, after which the current was broken and the hydrogen, together with the foreign gases, pumped out. If now, on closing the circuit for a moment, the dark space proved long enough, the current was applied for 1 minute; the canal rays generally showed at first a red color, but changed quickly into a bluish white. When this happened, then as before fresh hydrogen had to be admitted and the impurity pumped out. These operations were repeated until the canal rays in hydrogen would maintain their red color for about 15 minutes. In general, this state of purity was obtained after something like 5 hours of treatment such as that described.

Tubes were employed for making spectrograms only after they had shown the proper degree of purity; but it often happened that, during exposure, tubes gave off new impurities, so that the canal rays would change color. Or, on the contrary, the gas-pressure would diminish and the cathode-drop rise in consequence of self-exhaustion due to the electric current. For this reason the gas-pressure had to be renewed constantly—every 5 to 25 minutes—during the exposure; fresh gas was introduced either to sweep out impurities or to raise the pressure.

It has been shown by E. Goldstein that the path of the canal rays, in the region behind the cathode, depends upon the curvature of the front surface of the cathode; and I have elsewhere[1] fully described the manner in which the direction of the canal rays is connected with the curvature of the electric lines of force in front of the cathode.

If the front surface of the cathode is convex outward, then the

[1] "Die Electrizität in Gasen," *Winkelmann's Handbuch*, 4, 602, 1905.

canal rays converge behind the cathode (Fig. 3*a*); but if the front surface is concave, they diverge (Fig. 3*b*). Behind a plane cathode the canal rays generally converge to a slight extent; accordingly, one must make the front surface of the cathode slightly concave in order to obtain parallel rays (Fig. 2). This was done in most of the tubes used for my photographs.

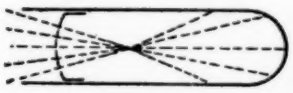


Fig. 3*a*

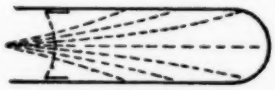


Fig. 3*b*

The spectrograms of canal rays were taken either with a prism spectrograph or with a Rowland concave grating. The former has already been described elsewhere;[1] the latter was kindly loaned me by Professor Runge near the end of my observations. The grating had a radius of 1 m, with 590 rulings to the millimeter, and an aperture of 8.6 cm. It was mounted in the manner employed by Professor Runge, with slit, spectrum, and center of grating on a circle; the camera was large enough to photograph at once the entire first order, and the second as far as λ 5000. The scale of the first order was 16.4 A. U. to the millimeter. Sometimes I projected the image of the canal rays upon the slit with the aid of a lens; generally, however, the slit was placed close up against the tube to obtain greater intensity.

The canal rays take their rise in different cross-sections of the region in front of the cathode, so that they complete a part of their course before reaching the canals of the cathode. The first cathode glow, so called, emits the spectrum of canal rays around this region. I have also taken several spectrograms of the first cathode glow. But these I shall not discuss here, confining my attention to spectrograms of canal rays obtained behind the cathode. On the front of the cathode there occurs a partial reflection of canal rays (§ 9), which is liable to introduce complications.

§ 3. *Character of the Doppler effect.*—To begin with, the direction of observation was chosen perpendicular to the beam of canal rays. An examination of the spectrograms, in the case of hydrogen, shows

[1] *Annalen der Physik*, **16**, 493, 1905.

that the region traversed by the canal rays in the rear of the cathode emits both the line[1] spectrum and the band[2] spectrum. By band spectrum we mean the so-called second or many-lined spectrum of hydrogen, which will be more fully discussed in § 10; at this point we consider only the line spectrum, including the series $H\alpha$, $H\beta$, ... But $H\alpha$ was not observed, owing to the small sensitiveness of photographic plates in this region.

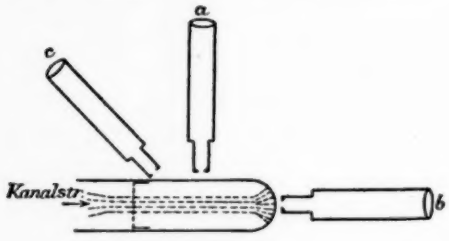


Fig. 4

The normal direction of observation is indicated by *a* in Fig. 4; in the position marked *b* the canal rays are directed "end on" toward the observer; while in position *c* they make an angle of 45° with the direction of observation.

In Figs. 5*a*, 5*b*, and 5*c* the wave-lengths are plotted as abscissae, the intensities as ordinates. These figures represent the appearance of the hydrogen lines observed ($H\beta$, $H\gamma$, $H\delta$, $H\epsilon$, $H\zeta$, $H\eta$) for the three different positions of observation. In the case represented by

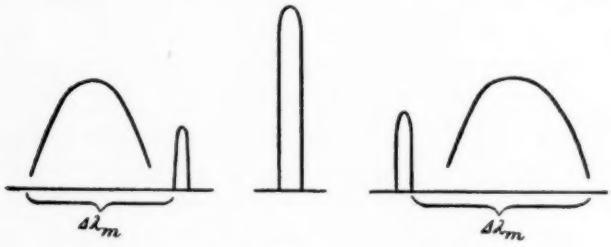


Fig. 5*c* Fig. 5*a* Fig. 5*b*

Fig. 5*a* the hydrogen line appears strong at the position in the spectrum where it is ordinarily seen. In the cases represented by Figs. 5*b* and 5*c* the hydrogen line is also seen in its usual position; but now its intensity is much less than in Fig. 5*a;* besides, it is accompanied (on the blue side in 5*b*, and on the red side in 5*c*) by a broad,

[1] A. Wüllner, *Physikalische Zeitschrift*, **1**, 132, 1899; E. Goldstein, *Ann. d. Physik*, **64**, 44, 1898; *Physikalische Zeitschrift*, **1**, 133, 1899.

[2] J. Stark, and W. Hermann, *ibid.*, **7**, 92, 1906.

hazy band. The presence of this band is explained as a Doppler effect produced by the translation of the carrier of the hydrogen series with reference to the observer. The intensity of the band is ascribed to the hydrogen particles in motion and may be called the "displaced intensity;" the intensity of the line which remains at its usual wave-length may be assigned to those hydrogen particles which have a small velocity relative to the observer, and may be called the "stationary intensity."

As is shown by Figs. 5*b* and 5*c*, the region behind the cathode emits simultaneously both displaced and stationary intensities; but the intensity observed in 5*a* results from the addition of the stationary and displaced intensities.

If in the canal rays behind the cathode there were only a single velocity, then we might expect, according to Doppler's principle, a displaced line, which would be sharp and of the same breadth as the stationary line. From the fact that the displaced line is a broad band, we may therefore infer that in the rear of the cathode the canal rays travel with various speeds. These different speeds are to be measured by the difference of wave-length $\Delta\lambda$ between the displaced intensity and the nearest edge of the stationary line. Then by Doppler's principle we have $v=c\left(\frac{\Delta\lambda}{\lambda}\right)$, where v is the velocity of the luminous source with reference to the observer, c the speed of light, and λ the stationary wave-length.

There are two causes which may bring about these different velocities in the rear of the cathode. First, the canal rays may originate in different cross-sections of the region in front of the cathode, and may therefore drop through different ranges of potential before reaching the canals; or, secondly, those rays which leave the canals with the same velocity may lose different proportions of their translational energy by collision with gas particles in the rear of the cathode.

One striking feature of the Doppler effect is that between the stationary line and the displaced intensity there is an intensity minimum. This may arise either from the fact that low velocities are not very frequent or that they are in some way connected with small intensities. In § 14, Part II, we shall again consider the origin of this minimum and of the stationary line.

What concerns us here especially is the maximum value of the displacement $\Delta\lambda_m$, that is, the distance of the outer edge of the band from the inner edge of the stationary line. This maximum

Fig. 6*a*

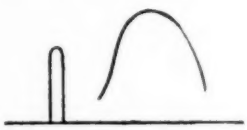


Fig. 6*b*

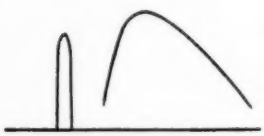


Fig. 6*c*

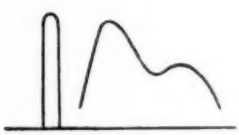


Fig. 6*d*

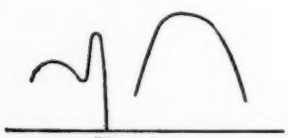


Fig. 6*e*

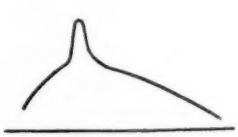


Fig. 6*f*

a, a single speed;
c, *e* { many low speeds; few high speeds;
e, reflection on glass wall;
b, a single maximum;
d, two maxima;
f, dispersion in a heavy gas.

displacement measures the maximum speed of the line-sources in the rear of the cathode, namely, $v_m = c\left(\frac{\Delta\lambda_m}{\lambda}\right)$.

The maximum velocity of the canal is computed as follows:

$$V_m = \sqrt{2\left(\frac{\epsilon}{\mu}\right)\Delta V},$$

where ϵ is the charge and μ the mass of a canal ray particle, and ΔV the cathode-drop in potential.

The Doppler effect, as described above, may be called *normal;* it is what one obtains when the gas is pure, and the cathode-drop is kept constant during the exposure for the spectrogram. For the sake of completeness, however, some other types are described in Figs. 6*a–f*. Fig. 6*a* illustrates the hypothetical case in which the canal rays have only one velocity; Fig. 6*b* represents the normal type; Fig. 6*c* shows the effect on a plate exposed for a short while

with a large cathode-drop and a long while with a smaller cathode-drop; Fig. 6*d* is obtained when the two different values of the cathode-drop are widely different; Fig. 6*e* illustrates a case to be described later, namely, that of the reflection of canal rays on a glass wall; and Fig. 6*f*, the case of dispersion of canal rays in a heavy gas—a phenomenon which will also be described below.

§ 4. *Constancy of the Doppler effect within any one series.*—There are two constant errors which may affect the measurement of the quantity which we have called the maximum displacement, i. e., the distance between the outer edge of the band and the nearest edge of the stationary line. First, if the stationary line is strong, its image spreads upon the photographic plate and gives an abnormal width, thus making the maximum displacement too small. Secondly, the outer edge of the band is generally diffuse, so that in setting upon its boundary one is apt to make the maximum displacement again too small.

Table I, obtained from a grating spectrogram, gives the maximum displacement for the hydrogen lines $H\beta$, $H\gamma$, $H\delta$, and $H\epsilon$, and also the largest velocity of the corresponding carrier (*Träger*). Taking into consideration the constant error, one might say that the maximum velocity of the carrier is the same for all hydrogen lines.

TABLE I

Wave-Length λ	Max. Displacement $\Delta\lambda_m$	Mean Error	Constant Error	Velocity $c\frac{\Delta\lambda_m}{\lambda}$
$H\beta$ 4861.5	7.58 Å.	0.18	$\Delta\lambda_m$ too small	$4.67\ 10^7$ cm.sec^{-1}
$H\gamma$ 4340.7	7.17	0.12	.....	$4.95\ 10^7$
$H\delta$ 4101.8	6.25	0.12	$\Delta\lambda_m$ too small	$4.57\ 10^7$
$H\epsilon$ 3970.2	5.12	0.12	$\Delta\lambda_m$ too small	$3.87\ 10^7$

All hydrogen lines have, therefore, the same carrier.

Arguing from the homology which exists between the series lines of the chemical elements, one may perhaps make the following generalization. All lines of one and the same series belonging to a chemical element have the same carrier. This theorem has been verified also in the case of mercury, for which see communications in the *Annalen der Physik*, No. 13 of 1906. If all the lines of the series are emitted by one and the same carrier, then it is to be expecte d

that their wave-lengths will be connected by formulae such as have in fact been discovered by Balmer, Rydberg, Kayser and Runge.

§ 5. *Electric charge of the carrier of the hydrogen series.*—Is the carrier of the hydrogen series a neutral hydrogen atom or a positively charged hydrogen ion? The canal rays themselves, in hydrogen, consist, according to the measurements of W. Wien,[3] of positive hydrogen ions moving with high velocity. If the ions of the canal rays are the sources of the series lines, then it is clear that the series lines must show the Doppler effect. If, however, the series lines have their origin in the neutral atom, then it remains to be explained how the neutral atom acquires the high velocity which the Doppler effect would seem to indicate.

It may be that the ions of the canal rays have a high velocity and yet emit no spectral lines; when now they collide with neutral atoms, they transfer velocity to these, and thus produce emission of the series lines. There are several facts, however, with which this explanation is not in harmony. First, the displaced line does not diminish in intensity when the gas-pressure is lowered, thus making the collisions less frequent (see Part II.) Secondly, in the case of mercury, one finds three groups of lines for which the squares of the reduced maximum displacement $\left(\frac{\Delta\lambda_m}{\lambda}\right)^2$ are in the ratio 1 : 2 : 3. Thirdly, neutral hydrogen which has not been ionized does not absorb the wave-lengths $H\alpha$, $H\beta$, ... even when thick layers of the gas are employed.

The assumption, on the other hand, that the series lines have their origin in the charged ions of the canal rays implies these very facts as necessary consequences. It is therefore highly probable that the carriers of the series lines in hydrogen are the positive hydrogen ions.

From the cathode-drop (ΔV) and the maximum displacement ($\Delta\lambda_m$) the specific charge $\left(\frac{\epsilon}{\mu}\right)$ for the hydrogen rays may be computed. Table II contains the data for this purpose derived from one series of spectrograms. The first column gives the line on which the maximum displacement was measured; the second, the cathode-

[1] *Annalen der Physik*, **5**, 421, 1901; **8**, 257, 1902; **9**, 660, 1902; **13**, 669, 1904.

TABLE II

Lines Measured	Observed Cathode Drop (Volts)	Computed Speed (Volts)	$\frac{\epsilon}{\mu}$ from Observed Cathode Drop and Maximum Displacement
$H\delta$.....	5000	1800	$3.42 \cdot 10^3$
$H\delta$.....	4200	1600	$3.61 \cdot 10^3$
$*H\delta$	4200	1600	$3.61 \cdot 10^3$
$H\delta$.....	2500	1400	$5.32 \cdot 10^3$
$H\gamma$.....	2500	1300	$4.94 \cdot 10^3$
$H\delta$.....	2000	1100	$5.22 \cdot 10^3$
$*H\delta$.....	3000	2100	$6.65 \cdot 10^3$

drop as observed on an electrometer during exposure; the third, the kinetic energy ($\frac{1}{2}\mu v^2$) in volts as computed from the maximum displacement, on the assumption that for the "carriers" $\frac{\epsilon}{\mu}=9.5\times10^3$ electromagnetic units; the fourth column gives the value of the specific charge $\frac{\epsilon}{\mu}$, computed from the formula

$$\frac{\epsilon}{\mu}=\frac{c^2}{2\Delta V}\left(\frac{\Delta\lambda_m}{\lambda}\right)^2,$$

where ΔV is the observed cathode-drop.

We shall now consider whether the method of computing the fourth column is justified. $\Delta\lambda_m$ is affected by a constant error which makes its observed value too small, whence the computed value of $\frac{\epsilon}{\mu}$ is always less than it should be. The value employed for ΔV is the largest value of the potential-difference through which the ions of the canal rays pass. Now, first of all, it is possible that the ions in front of the cathode do not experience the whole, but only a part, of the potential drop ΔV; and, secondly, the results of Part II show it to be a fact that, in the region behind the cathode, the canal rays lose kinetic energy through radiation; and hence the farther the canal rays travel, the less their speed. If, therefore, in the computation of $\frac{\epsilon}{\mu}$ the observed values of the cathode-drop ΔV are employed, too small a value of $\frac{\epsilon}{\mu}$ will always be obtained.

Accordingly, the values of $\frac{\epsilon}{\mu}$ given in column 4 of Table II represent merely the lower limit of the actual value. In other words, the specific charge of the "carrier" of the hydrogen series is greater than 6.6×10^3.

W. Wien has determined the largest value of $\frac{\epsilon}{\mu}$ for hydrogen to be 9.5×10^3; this is for a univalent positive hydrogen ion. A bivalent hydrogen ion would have a specific charge $\frac{\epsilon}{\mu}=19\times10^3$. It is not at all likely that the value obtained by me is the lower limit of 19×10^3; it is more probable that the actual value of $\frac{\epsilon}{\mu}$ for the carrier of the series is 9.5×10^3, and that this carrier is therefore the univalent positive hydrogen ion.

One seems to be justified, therefore, in assuming the value 9.5×10^3 in computing the third column. A comparison of this with the second column shows that the actual kinetic energy of the canal rays behind the cathode is greater in proportion as the cathode-drop is greater, but that the former is always from 30 to 60 per cent. less than the latter.

A word may be said here concerning the diminution of speed in canal rays, mentioned above and described more fully below. In Table II there are two horizontal rows marked by an asterisk. In the case of the upper line, the collimator tube was placed in the position *b* of Fig. 4, while in the case of the lower line it was in the position *c;* the portion of the tube in the rear of the cathode was 15 cm long. In the *b* position the ratio of the computed to the observed cathode-drop was, according to the table, $\frac{1\,6\,0\,0}{4\,2\,0\,0}=\frac{8}{2\,1}$; while for the *c* position this amounted to $\frac{2\,1\,0\,0}{3\,0\,0\,0}=\frac{7}{1\,0}$.

§ 6. *Electric charge of the carriers of series of doublets and triplets, complexity of the line spectrum of an element.*—Using the notation of Kayser and Runge, the hydrogen series *Hα*, *Hβ*, ... is a first subordinate series of doublets, the frequency-difference of its components being 0.33. From what precedes we may infer that the carrier of this first subordinate series of doublets is a univalent positive hydrogen ion.

In another article it will be shown that the carrier of the principal

series of doublets of potassium is probably a univalent potassium ion.

As will be seen from a later paper, on the Doppler effect with mercury, there appears in the mercury spectrum a line (λ 2536) whose carrier is a univalent mercury ion. From the homology existing between this and certain lines in the spectra of zinc and cadmium we may infer that this line also belongs to a series of doublets.

These three cases, in which the series of doublets have a univalent positive ion for carrier, lead one to conclude, on the basis of a widespread homology, that in general the carriers of series of doublets are univalent positive ions.

Among series of doublets are to be reckoned the principal series, the so-called first and second subordinate series of doublets, and the line-series, called by Rydberg "secondary series," which accompanies the first components of the first subordinate series on the blue side. We may suppose all of these series to have the same univalent positive ion as carrier; indeed it is quite possible that this ion emits, besides the above mentioned and known series, still other lines whose place in the series of doublets has not yet been recognized.

If the different series are due to one and the same carrier, as is the case with the different members of a single series, then we might expect some systematic relation between the different series such as has already been found between the various members of a single series; in consequence of their having a common source, there would be certain conditions connecting them one with another. And this is, in fact, the case. For, according to Rydberg,[1] the pairs of the first and second subordinate series have the same frequency difference; in addition to this, the two series have the same convergence frequency. The second subordinate series of doublets is related to the principal series by the fact that their first terms ($m=1$) are numerically identical, as shown by the equation

$$\frac{n}{N_0}=\frac{1}{(1+\mu)^2}-\frac{1}{(m+\sigma)^2}.$$

The components of each member of this subordinate series exhibit the same Zeeman effect as those of the principal series but in reversed order.

[1] *Svenska Vet. Ak. Handl.*, **23**, No. 11.

As will be shown in the following paper on mercury, the two subordinate series of mercury triplets have a bivalent mercury ion as carrier; this probably emits, besides the series, other lines which, having a simultaneous origin in similar sources, are probably related with the series of triplets. The two subordinate series of triplets of course satisfy the condition that their convergence frequencies should be the same, and that the frequency difference between the components of the members should be equal. In the case of mercury there appear, in addition to lines which have a univalent or bivalent carrier, also lines whose carrier is trivalent, as, for instance, λλ 4078 and 4347. According to § 15, these apparently belong to a term in which no less than seven components are associated. It is probable that trivalent ions emit series, and that the number of components in each term of the series is greater than three.

Univalent ions emit series lines of two components; bivalent ions emit series of triplets; ions of higher valency should emit series of which the members have more components in proportion as the valency increases.

Series having members of more than three components have not yet been discovered. However, Kayser and Runge[1] have found that in the spectrum of bismuth there are quadruplets, and in antimony sextuplets, with constant frequency differences which repeat themselves. C. P. Snyder[2] has found in the spectrum of rhodium a group of 19 lines repeated as many as 54 times. The chemist finds bismuth and antimony to be trivalent and pentavalent; in like manner rhodium is bi-, tri-, and quadri-valent.

From what precedes it would appear that the higher the valency of an ion becomes, the more numerous are the components in its series lines, and therefore the more complex is its spectrum. If we are to believe that chemical valence also cuts an important figure in spectroscopy, we may also expect that any element will give a spectrum richer in lines in proportion to its chemical valence and in proportion to the number of ions of different valencies which it is able to form. And this appears to be the fact of the case. In Table III are given the elements of a single horizontal row of the periodic

[1] *Abhandl. d. Berlin Akad.*, 1894.

[2] *Astrophysical Journal*, **14**, 179, 1901.

system, together with their chemical valencies and their arc and spark lines.

If at the temperature of the arc or of the spark any element produces several different kinds of ions, then the resulting line spectrum consists in the superposition of the spectra of these different sorts of ions.

TABLE III

Element	Valency	Lines in the Arc	Lines in the Spark	Region of Spectrum	Observer
K	1	41		2942.8—7699.3	Kayser and Runge
			133	2341.7—7699.3	Eder and Valenta
Ca	1, 2	106		2200.84—6499.85	Kayser and Runge
			165	2081.53—6499.85	Eder and Valenta
Sc	1, 3	110		3907.62—5717.54	Lockyer and Baxandall
			142	2232.98—4744.02	Exner and Haschek
Ti	2, 3, 4	865		3477.33—5899.65	Hasselberg
			1337	2154.80—4698.93	Exner and Haschek
Vd	1, 2, 3, 4, 5	627		3094.79—5786.41	Rowland and Harrison
			2431	2131.8 —4670.65	Exner and Haschek
Cr	2, 3, 6	770		3433.42—5797.02	Hasselberg
			1572	2173.44—4601.2	Exner and Haschek
Mn	2, 3, 4, 7	1233		2346.58—5748.75	Fritsch
			1152	2215.31—4709.90	Exner and Haschek
Fe	2, 3, 4, 6	4620		2230.01—6750.36	Kayser and Runge
			2290	2068.25—4736.96	Exner and Haschek

The ratio of intensities in the different spectra depends upon the degree of dissociation for each valency, and upon the temperature when the amount of dissociation remains constant. In the spectrum of copper there are triplets[1] as well as doublets; so also in the spectra[2] of *Mg, Ca, Sr, Ba, Ra, Zn, Cd, Hg;* in the spectra of the last three elements there appear, beside doublets and triplets, still other lines. The line spectra of *Li, Na, K, Rb,* and *Cs* are dominated by series of doublets; and they are found again, together with other lines in the spectra of *Au, Ag, Al, In,* and *Tl.*

§ 7. *Conclusions concerning ionization and emission of light.*— According to the preceding pages, the carriers of line spectra of the elements are the positive ions. A vapor which is emitting a

[1] J. R. Rydberg, *Astrophysical Journal,* **6**, 237, 1897.

[2] Runge and Paschen, *Abhandlungen der Berlin Akad.*, 1902.

line spectrum is therefore necessarily an ionized or electrically conducting substance. A special case of this general theorem is the following. When a bead of some alkali salt is introduced into a Bunsen flame, there appears simultaneously the line spectrum of the alkali and a marked increase of electric conductivity in the flame. The particles which emit the line spectrum are the positive ions and not the neutral atoms of the alkali; the number of luminous particles involved in the line spectrum is therefore less than the number of atoms introduced into the flame; it is proportional to the degree of electrical dissociation, i. e., to the ratio of the number of positive ions to the total number of atoms introduced. H. A. Lorentz[1] shows, on theoretical grounds, that the number of luminous particles in the Bunsen flame producing the line spectrum is much smaller than the total number of atoms of the alkali introduced. From his computation and from the results of E. Wiedemann[2] the ratio of these numbers is, in the case of a sodium salt, 2.4×10^{-2}.

The converse of the above theorem is that when a gas becomes electrically conducting or is ionized it emits a line spectrum. This proposition, however, is not true; for the emission of a line spectrum depends not simply upon the presence of positive ions, but requires also that the temperature shall be sufficiently high. Yet absorption is perceptible at all temperatures. We may therefore conclude that a gas absorbs its line spectrum from a transmitted beam when there is present in the gas a large number of positive ions; but if this condition is not satisfied, the gas does not absorb its line spectrum. It is known that the oxygen and nitrogen of the Earth's atmosphere do not absorb their line spectra from sunlight even though passing through such an enormously thick layer; the number of positive ions in the atmosphere is exceedingly small. In like manner, thick layers of non-ionized mercury vapor or of hydrogen will not, at moderate temperatures, absorb the slightest trace of their line spectra.

§ 8. *Widening of spectral lines by increase of density.*—The width of spectral lines can be increased without rise of temperature by merely increasing the density of the luminous vapor. This kind of widening is not caused by the Doppler effect, but rather by a force

[1] *Proceed. Akad. Amsterdam,* 1905, p. 591.

[2] *Annalen der Physik,* **37**, 212, 1889.

which deforms the radiant ion and thus changes the period of the lines emitted.

W. Voigt[1] has shown on theoretical grounds that the electrical force acting upon a radiant particle would by deformation alter the wave-length of its spectral lines. According to H. A. Lorentz,[2] a disturbance of the radiation, and hence a widening of the line, would occur long before the radiant particle had traversed the free path assigned to it by the theory of gases; in other words, a radiant particle is subject to distorting forces even when its distance from other particles is much greater than the diameter of the sphere of action demanded by the kinetic theory.

The radiation of the positive ion occurs in the electric field of the positive charge; and this field, even at a considerable distance from the ion, has a large value. The sphere of action of the positive ion is therefore greater than that of the neutral atom. The distorting force between a positive ion and another particle would be effective at greater distances than the force acting between two neutral particles.

§ 9. *Reflection and dispersion of canal rays.*—The reflection of hydrogen rays by glass has already been described by W. Hermann and S. Kinoshita,[3] and we here merely add some numerical data. With a grating spectrogram I have measured the maximum displacement $\Delta\lambda_r$ (see Fig. 6*e*) due to the Doppler effect for the reflected $H\beta$ and $H\gamma$ rays; the speed of the incident rays as computed from their maximum displacement $\Delta\lambda_i$ was from 4.67 to 4.97 $\times 10^7 \frac{\text{cm}}{\text{sec}}$ (1300 volts). The quantity $\left(\frac{\Delta\lambda_r}{\Delta\lambda_i}\right)^2$ gives the fraction of the incident energy which is reflected by the glass wall. In the case just cited this amounts to 0.35 for $H\beta$, and 0.18 for $H\gamma$. The impact of a hydrogen ion against a solid glass wall is therefore not perfectly elastic; nor is it perfectly inelastic; with a velocity due to a drop of 1,300 volts the ion loses, on impact, from 65 to 82 per cent. of its initial energy and retains, after reflection, from 35 to 18 per cent. Hermann and Kinoshita have already observed the dispersion

[1] *Annalen der Physik*, **4**, 197, 1901.

[2] *Proceed. Akad. Amsterdam*, 1905, p. 591.

[3] *Physikalische Zeitschrift*, **7**, 564, 1906.

of hydrogen rays in a heavy gas. The following observations deal with the dispersion of hydrogen canal rays in hydrogen itself.

As already indicated in § 3, the sum of the stationary and displaced intensities is obtained when the tube is viewed in a direction at right angles to that of the canal rays. I have taken a larger number of spectrograms in this position under both high and low gas-pressures. On comparing these I find the following facts: With high pressures the strong line when viewed normally appears upon a weakened darkened background, as indicated in Fig. 7*a*. When the gas-pressure is lowered, the intensity of the background diminishes and the line itself becomes sharper (Fig. 7*b*); at still lower pressures the background ceases to be visible even when the intensity of the line is very great (7*c*). This peculiar widening of the hydrogen lines at higher pressures may be explained in the following manner. A small portion of the canal rays originally moving along a straight path at right angles to the line of sight collide with hydrogen molecules, and are reflected by these to one side so as to acquire a velocity component in the line of sight, either toward or away from the observer. Therefore both to the right and to the left of the undisplaced line we have the Doppler effect. The intensity, however, will diminish as the number of collisions of canal rays with neutral gas particles diminishes, i. e., as the gas-pressure diminishes. Even with the naked eye it is seen that canal rays in hydrogen are less diffuse as the pressure diminishes.

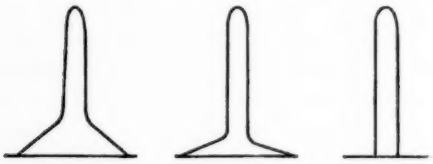


Fig. 7*a* **Fig. 7*b*** **Fig. 7*c***

§ 10. *The line at* λ 4688, *and the banded spectrum of canal rays.*— Starting from the second subordinate series, J. R. Rydberg[1] has computed the wave-length of the first line in the principal series of hydrogen to be 4687.88. In some bright stars there is, besides the known hydrogen lines, a strong line at λ 4688.

Hasselberg[2] has measured the wave-lengths of a large number of lines in the banded spectrum of hydrogen; and among these he

[1] *Astrophysical Journal*, **6**, 233, 1897.

[2] *Mem. de l'Acad. de St. Petersburg*, VII, ser. XXXI, No. 14.

counts the lines at λ 4689.39 and λ 4685.97. Both of these lines I have found on all of my spectrograms. In the spectrograms of the negative glow and in the spectrograms of the canal rays, observed when the line of sight is perpendicular to the rays, the space between the two lines is bright; but in the spectrograms taken in the positions *b* and *c* of Fig. 4 the interval between the two lines is filled with a dark, weak, hazy band.

In my preliminary paper I thought I saw in this band the Doppler effect of a line at λ 4688, and considered it the first line of the principal series. Yet, in spite of many attempts with later and better spectrograms, I have not succeeded in accurately determining the wave-lengths of the edges of this band; the difficulty lies in the small intensity of the band and in the proximity of the two lines in the banded spectrum. I cannot therefore conclude that the line at λ 4688 and its Doppler effect have been shown on my plates.

As already mentioned, the region which is traversed by canal rays emits both the linear and the banded spectra of hydrogen. The lines of the banded spectrum are sharp and narrow, but they never show any Doppler effect either in the negative glow, or in the glow which covers the cathode, or in the space traversed by the canal rays; and this is true whatever be the direction of observation. From these facts we may infer the following: The banded spectrum and the line spectrum of hydrogen do not have the same carrier; the banded spectrum is not emitted by the positive hydrogen ion. The carrier of the banded spectrum has neither a positive nor a negative charge; for an electric field does not impress upon it a velocity in any direction. Nor is the banded spectrum emitted by neutral hydrogen atoms which are brought into luminosity by collision with canal rays; for in this event the colliding hydrogen atom would receive from the incident canal ray, not merely internal energy, but also energy of translation. Besides this, it is to be remembered that hydrogen which is not ionized will not absorb, even in great thicknesses, the slightest trace of its banded spectrum.

A good while ago I suggested[1] that the banded spectrum of an element is produced at the instant when positive ions unite with negative electrons and is emitted by the neutral system formed by

[1] *Annalen der Physik*, **14**, 525, 1904.

the parts thus uniting. In a later paper[1] I have shown how easily and naturally the properties of banded spectra flow from this hypothesis. But to avoid misunderstanding, the following remarks are added.

By banded spectra are meant those which we observe as a secondary phenomenon in ionization and in electric currents in gases. The banded spectrum which appears in certain gases, such as oxygen and iodine vapor, independently of ionization or of electric conduction, is not the one here discussed. This belongs rather in the group of spectra of compounds, as illustrated by carbon dioxide and water vapor; also by a series of oxides and halogen compounds when used in the Bunsen flame. This latter spectrum apparently has its origin in the reaction between the parts of the molecule, just as the former has its origin in the reaction of the negative electrons upon the positive ions.

The lines of a banded spectrum differ from those of a line spectrum in the following respect: at high temperatures the former disappear in a continuous background, while the latter increase in intensity. The Doppler effect is not to be expected in the lines of bands, but only in those lines which become intensified by rise of temperature; these are precisely the lines which belong to the line spectrum; they are strong in the arc and still stronger in the condensed spark.

This hypothesis concerning the carriers and the constitution of banded spectra resembles, in some points, the view expressed long ago by E. Wiedemann,[2] that the line spectrum is a function of the separate atoms in the molecule, and that the quantity of heat which is necessary to transform the banded into the line spectrum is measured by the maximum value of the heat of dissociation of the hydrogen molecule.

[1] *Physikalische Zeitschrift*, **7**, 355, 1905.

[2] *Wied. Ann.*, **5**, 506, 1878; **10**, 252, 1880.

[*To be continued*]

THE ABSORPTION OF SOME SOLIDS FOR LIGHT OF EXTREMELY SHORT WAVE-LENGTHS

By THEODORE LYMAN

The observations recorded in this paper deal with that part of the spectrum discovered by Schumann which lies between λ 2000 and λ 1250 Ångström units. The region possesses considerable interest, for to the ordinary problems of spectroscopy—the radiation and absorption spectra of solids and gases, and the reflecting power of metals—must be added questions connected with the photo-electric effect and with the physiological action of light. The author's[1] determination of the wave-lengths of the hydrogen spectrum afford, it is to be hoped, trustworthy landmarks by which future investigations in the region may be guided. It next becomes necessary to improve, as much as possible, the facilities for such explorations.

The grating spectroscope[1] which the author used in previous work, though well adapted for wave-length measurement, is not convenient for general investigation. The large size of the vacuum receiver, 110 cm long by 11.3 cm in diameter, renders the process of exhaustion tedious; the length of the light-path within the apparatus, almost 2 m, exaggerates the importance of absorbing impurities in the gas; and the relatively small amount of light obtained in any one grating spectrum renders the study of feeble radiation difficult. The use of a prism spectroscope offers improvement in all these respects. The difficulty, however, of obtaining suitable prisms and lenses is considerable; white fluorite is the only substance which has been used in the past for this purpose, and even this very expensive material absorbs completely in the neighborhood of λ 1230—a point nearly two hundred units above the present limit of the spectrum.

The purpose of the present investigation was therefore purely a practical one—namely, to discover, if possible, some substance which should be as transparent as fluorite, and which should exist in clear

[1] *Astrophysical Journal*, **23**, 181–210, 1906.

masses of sufficient size to permit the manufacture of prisms and lenses. Of course, the discovery of some material more transparent than fluorite would be most welcome, even if it existed only in small crystals; for such a substance would serve the much-needed purpose of a window for the large vacuum spectroscope.

In testing the transparencies of a large number of substances for light of very short wave-length the method described in a former paper,[1] though accurate, is tedious. The author has, therefore, constructed a new instrument for the purpose. In it the photographic plate is replaced by a fluorescent screen coated with willemite, and the place of grating is taken by a concave mirror and fluorite prism. The construction may be understood by referring to Fig. 1. A brass casting, with a cavity of circular cross-section 8 cm in diameter, contains the mirror and the prism; the top of the casting is closed air-tight by a plug which screws into place. Into the sides of the casting, and nearly at right angles to each other, fit two brass tubes. One of these tubes 21 cm long carries a flange at its far end closed air-tight by a glass plate. The fluorescent screen *P* is placed a few centimeters from this plate and may be observed through it. The other tube carries the source of light. In order to secure the necessary brilliancy of illumination, no slit is used, the end of the capillary of a discharge tube serves itself as the source. The details of the arrangement are shown in Fig. 2. One electrode of the tube is formed by a platinum wire sealed in the usual manner, while the other electrode is the brass casting itself. Thus, when the apparatus is exhausted the discharge passes from the platinum along the capillary to the sides of the casing, the end of the tube, some 0.9 mm in diameter, furnishing a bright point of light. The bits of the substances whose transparencies are to be examined are fastened over the holes of the disk shown in the illustration. This disk can be rotated through a simple cog mechanism, by a key fitting air-tight in the screw cover which closes the end of the casing tube. By this rotation the specimens are brought in turn before the end of the capillary and at a distance of about 6 mm from it.

The mirror employed is of speculum, radius of curvature 25 cm, and the mounting is of a very simple form permitting movements

[1] *Loc. cit.*, p. 196.

about horizontal and vertical axes. The prism is of excellent white fluorite, by Zeiss, angle 60°; it is mounted on a table fitted with leveling screws.

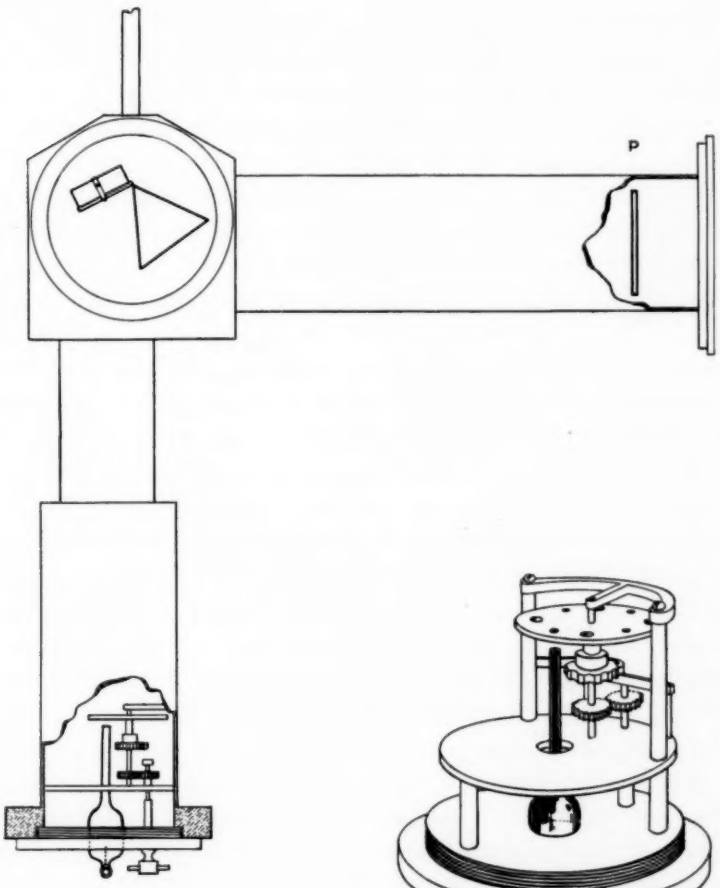


FIG. 1

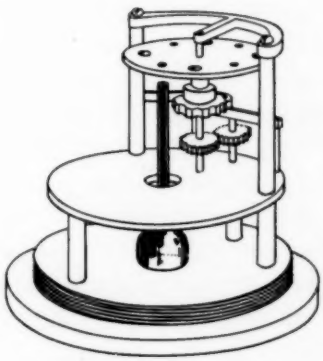


FIG. 2

The exact dimensions are not essential to the success of the apparatus; Fig. 1 is one-third, and Fig. 2 is two-thirds, of natural size. It is worth noting that the screw-joints which close the prism-chamber and one of the casing tubes have proved more satisfactory than

flanges with ground plates. In order to secure an air-tight joint, it is necessary only that the screw-threads be carefully cut and well covered with stopcock grease. Brass apparatus made from castings are almost sure to contain pin-holes, but the resulting leak may be reduced to a minimum by the use of thin shellac.

It is obvious that the optical arrangement of the apparatus is such that no great perfection of definition is to be expected. For the rough tests for which the instrument was constructed this, however, is not a serious drawback.

The operation of the instrument is as follows. The mirror and prism are so adjusted that the lines at the extreme ultra-violet end of the aluminum spectrum at λ 1854 fall on the end of the fluorescent screen. This arrangement is secured by the use of an aluminum spark in air and a slit temporarily placed in the casing tube at the point usually occupied by the end of the discharge capillary. A piece of fluorite of known transparency is then fastened over one of the holes in the movable disk, a second hole is left open, while the remainder are closed with pieces of the substances whose transparencies are to be tested. The temporary slit is now removed, and the face-plate with its discharge capillary and revolving disk is screwed into place. The casing is now connected with a vacuum pump, and the pressure is reduced to a value of about 0.3 mm of mercury. The apparatus is then washed three or four times with dry hydrogen, the pressure being finally reduced to 3 or 4 mm. The observer, seated in a darkened room, starts the current through the discharge capillary; with no absorbing medium in the light-path, the spectrum will then be seen to extend quite across the fluorescent plate—a distance of about 5 cm. Next, by turning the key on the outside of the face-plate, the fluorite and other absorbing substances come in succession in front of the capillary, and their effect on the length and brilliancy of the spectrum is determined. In practice it was found convenient to use a piece of quartz for comparison in many cases, since most of the substances tested were far inferior in transparency to colorless fluorite. The results obtained by these eye observations were checked in all important cases by the photographic method, the large grating spectroscope being used for this purpose in a manner described in the former paper. Comparison showed that the rough prism instru-

ment could be trusted to detect the difference in transparency of two substances the length of whose spectra, when obtained photographically, differed by not more than fifteen Ångström units. If it be remembered that the object of the investigation was a purely practical one, it will be seen that this prism instrument fulfils the purpose for which it was intended. The arrangement of mirror, prism, and fluorescent screen may be employed for other purposes than that of measuring the absorption of solids; for, if the open capillary is replaced by an "end-on" discharge tube closed by a fluorite window, sealed into the face-plate and separately exhausted, the apparatus serves to demonstrate the absorption of the air. If the discharge tube is excited and the casing is attached to a vacuum pump, the spectrum is seen to extend itself across the fluorescent screen as the pressure is diminished.

A further modification of the arrangement will permit of an approximate determination of the limit of reflection of metals in this region.

The transparency of the following substances has been tested.

Quartz.—Quartz in thicknesses of from 1 to 2 mm shows considerably greater transparency than was to be expected. Spectrum No. 5 of Plate I obtained with the grating spectroscope, shows lines to wave-length λ 1500. The slit-width was 0.09 mm, as in all the following cases; the source was a vacuum tube filled with air at about 1 mm pressure; the time of exposure was eight minutes. The light passed through the usual fluorite window before reaching the quartz plate.

Spectrum No. 4 shows the transparency of a column of quartz 2 cm long. The rapid increase of absorption with thickness here indicated explains why quartz prisms and lenses were found by Schumann to be useless for work beyond λ 1600.

Spectrum No. 3 shows the absorption of a quartz plate 0.2 mm in thickness. All these spectra as well as those which follow, were obtained with the same time of exposure, namely eight minutes.

As far as can be determined from an examination of fourteen specimens of colorless quartz between 1 and 2 mm thick, some selected from right-handed and some from left-handed pieces, and some from specimens cut parallel and perpendicular to the optic axis, the direction of rotation and of the axis makes no practical difference in the transparency of the material.

Fused quartz seems somewhat less transparent than the crystalline substance.

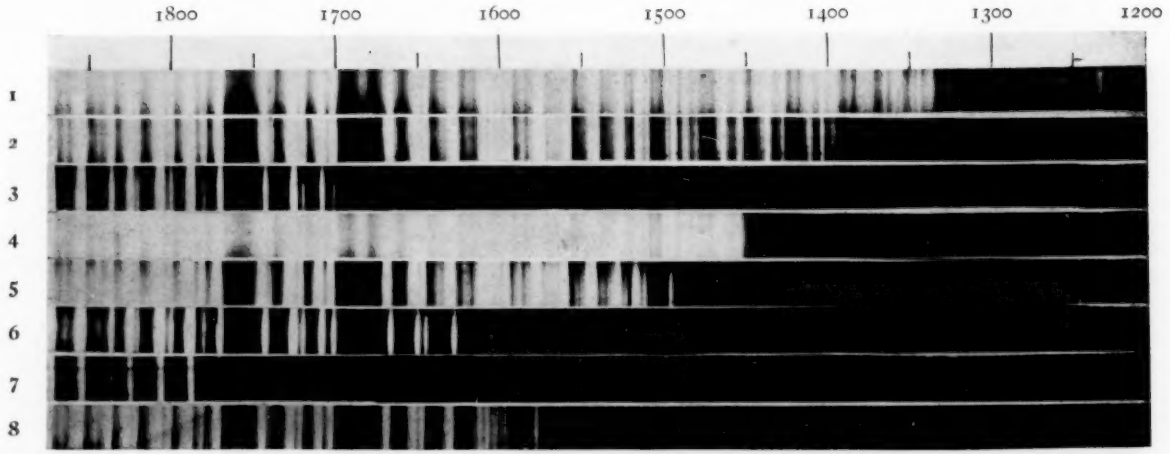
It appears, therefore, that in the region from λ 2000 to λ 1500 quartz in thickness of about 1 mm may be used in place of fluorite. Thick prisms or lenses, however, are useless in this region.

Fluorite.—Though clear, colorless fluorite is rare and expensive, the colored varieties are common enough, and sometimes may be obtained in clear masses of considerable size. Specimens cut from purple, green, pink, and yellow fluorites of various shades have accordingly been tested, which were usually in the form of plates from 1 to 2 mm thick. They show considerable range of transparency. A typical spectrum taken through a purple fluorite is shown in No. 3. Of fifty-seven specimens, forty-two were less transparent than this purple sample, ten were nearly equal to quartz 1 mm thick, and five were almost as good as colorless fluorite from Zeiss. From this test it appeared that the depth of color was a good indication of the absorption; the most deeply colored were the most opaque, while the five most transparent pieces were nearly, if not quite, colorless. There was one notable exception to this rule, however: four specimens from a light-green crystal from Westmoreland, N. H., were nearly as transparent as the plates from Zeiss, No. 1. No. 2 illustrates this fact. This crystal was free from flaws. There is some hope, therefore, that colored fluorite may yet be found which will serve for prisms and lenses, and which will possess the requisite transparency for use in the region between λ 2000 and λ 1250.

It is well known that the color may be removed from fluorite by heating, and, if the process is carefully carried on, no cracks are developed. This loss of color, however, is accompanied by only the very slightest gain in transparency, if any. In ten cases out of twelve no difference could be noted at all either by the visual or by the photographic method.

A microscopic examination with a power of two hundred diameters showed little difference in constitution between the transparent Westmoreland fluorite and the more opaque colored varieties. In general, the specimens which showed the greater absorption seemed to contain the larger number of those fluid-filled cavities which have been

PLATE I



TRANSMISSION OF EXTREMELY SHORT WAVES BY VARIOUS SUBSTANCES

1. Colorless Fluorite.
2. Green Fluorite.
3. Purple Fluorite.
4. Quartz, 0.2 mm thick.
5. Quartz, 2 mm thick.
6. Quartz, 20 mm thick.
7. Rock-Salt.
8. Ceylon Topaz.

so often observed. The colorless variety of fluorite from Zeiss was quite free from these microscopic inclosures.

The fluorescence excited by cathode rays was somewhat less brilliant in the colorless than in the colored fluorite, but the differences were not of such a magnitude as to give an indication of the relative transparencies of the specimens.

Topaz.—Next to the colored fluorites, topaz from Ceylon shows the greatest transparency of all the substances examined. The result obtained by the photographic method is shown in spectrum No. 8. The specimen was 1.5 mm thick; it is thus inferior to quartz. Topaz from Japan, Utah, and Siberia is much less transparent than that from Ceylon. It is possible, however, that this difference may be considered rather as a peculiarity of the individual specimen than as a distinctive property connected with a region.

Gypsum.—This substance, when examined in bits 1 mm thick bounded by cleavage surfaces, shows a spectrum which extends to the region between λ 1700 and λ 1650.

Celestite.—This substance, when examined in polished pieces 1 to 2 mm thick, shows a transparency about equal to that of gypsum.

Rock-salt.—The transparency is shown by No. 7, Plate I. The specimen was 2 mm thick, with well-polished faces. It is worthy of note that up to the present time some authorities have considered that rock-salt was as transparent as quartz to the extreme ultra-violet.[1] It is evident that in the region beyond λ 2000 for thicknesses of 1 or 2 mm this is far from true.

Barite.—In polished pieces 1 to 2 mm thick the transparency is about equal to that of rock-salt.

Alum.—Pieces cut from crystals and 1 mm thick show a spectrum ending near λ 1750, but of rather stronger intensity than that obtained with rock-salt.

Colemanite.—Transparent to the neighborhood of λ 1750.

Sugar.—Plates 1 mm thick cut from crystals of rock candy are less transparent than colemanite.

The test pieces of all the substances just mentioned were clear and free from flaws. The surfaces were carefully polished.

In addition to the above, the following substances were tested and

[1] Kayser, *Handbuch der Spectroscopie*, Vol. 3, p. 386.

found perfectly opaque to light of shorter wave-lengths than 2000; borax, adularia, calcite, chrysoberyl, sanidin, arragonite, apophyllite, silver chloride (horn silver), Kunzite, and diamond. Several of these are known to be opaque to light of longer wave-lengths than 2000. The tests were made in the hope of discovering some material which showed selective absorption to a marked degree.

In the case of diamond we have an example of a crystalline substance which is transparent to the visible part of the spectrum and to X-rays, yet which is apparently opaque to light of very short wave-length.

SUMMARY

Fluorite still remains the only known substance transparent to λ 1250 Ångström units. While colorless fluorite is in general far more transparent than the tinted varieties, yet colored fluorite does exist of sufficient transparency to serve in apparatus intended for the exploration of the region between λ 2000 and λ 1250.

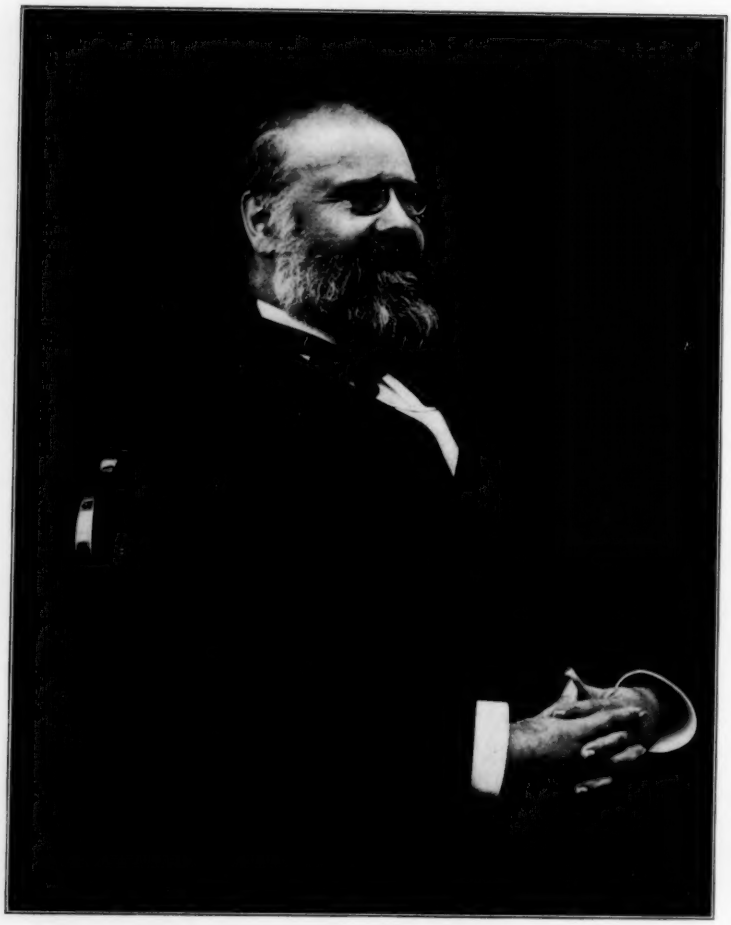
Quartz in thicknesses of from 1 to 2 mm is transparent to λ 1500. This is a useful fact, as it indicates that quartz windows may be employed to replace fluorite in those cases where the electric or physiological action of the strong portion of the hydrogen spectrum lying near λ 1600 is to be studied.

Of all the substances examined none show absorption bands in the region between λ 2000 and λ 1250. The apparatus employed in this examination, however, does not permit the investigation of this point by methods of great delicacy.

It is interesting to note that the fluorescent substance willemite responds to the action of light of extremely short wave-length.

JEFFERSON PHYSICAL LABORATORY
HARVARD UNIVERSITY
December 26, 1906

PLATE II



GEORGES RAYET

Minor Contributions and Notes

GEORGES RAYET

Science has suffered a severe loss in the sudden decease, on June 14, 1906, of M. Georges Rayet, founder, and for more than twenty-five years director, of the Observatory of Bordeaux.[1]

Born at Bordeaux on December 12, 1839, he became attached to the Observatory of Paris in 1862. Here he was more particularly occupied with the weather service, but he was also attracted by spectroscopy, then a new branch of research, and he undertook the spectroscopic study of numerous celestial objects. His published works during the following years deal with the spectrum of the Sun, prominences, and sun-spots; with the spectra of several comets, and with terrestrial magnetism and auroras. Some of his investigations were made in conjunction with M. C. Wolf, and together, in 1867, they discovered the three stars in *Cygnus* having bright lines in their spectra. The names of MM. Wolf and Rayet have been always associated with the spectra of this interesting type, the number of stars belonging to which has since been greatly enlarged. Present-day students of stellar spectra, dealing with photographs made with powerful instruments, are perhaps unable to fully appreciate the difficulties of the early visual spectroscopic observations of faint stars; such discoveries certainly deserve far more credit than those which may be made upon modern spectrograms.

At the solar eclipse of August 18, 1868, M. Rayet gave his attention to the spectra of the prominences, which were then objects of great interest and supposedly observable only at the time of an eclipse. He established the fact that the prominences contained other substances than hydrogen, and found the line D_3, subsequently ascribed to helium.

From 1874 to 1876 M. Rayet occupied the chair of physical astronomy of the faculty of sciences of Marseilles, and in 1876 became professor at Bordeaux in the same chair, which he was the first to

[1] This note is based upon facts kindly communicated by M. Ernest Esclangon.

occupy; and the duties of which he discharged for thirty years until his death.

The construction of an observatory at Bordeaux was decided upon in 1877, and M. Rayet was designated as director. The observatory began its activity in 1881, and for twenty-five years M. Rayet here worked steadily, making numerous observations on nebulae, double stars, and comets. He was a successful executive as well as scientist, and was devoted to the interests of the observatory to which he had given so many years of his life.

A LIST OF EIGHT STARS WHOSE RADIAL VELOCITIES ARE VARIABLE

The following stars have been found to be spectroscopic binaries. All of them, with the exception of *SU Cygni*, were discovered with the Mills spectrograph in the course of the regular observing program. Velocities expressed without decimals indicate either that the measures are preliminary and approximate, or that the type of spectrum does not permit accurate measurements to be made.

1 Geminorum ($\alpha = 5^h\ 58^m.0$, $\delta = +23°\ 16'$)

Plate	Date	Velocity	Measured by
2643 D	1903, January 4	+32. km	Curtis
		+33.7	Burns
4027 D	1905, September 27	+19.	Moore
4471 E	1906, October 1	+13.	Moore
		+15.7	Newkirk
4538 C	1906, November 9	+20.	Moore
		+20.5	Newkirk

This star is of type H. Its binary character was discovered by Mr. Moore.

B. A. C. 5890 = *D. C.* 7579 ($\alpha = 17^h\ 21^m.3$; $\delta = -5°\ 0'$)

Plate	Date	Velocity	Notes
1343 B	1899, July 18	+ 7.±km	lines single
1738 C	1900, May 20	−27.±	
3851 B	1905, June 21	+69.	strong component
		−82.	faint component
4314 B	1906, July 16	+ 4.	lines single
4324 B	1906, July 22	+29.	strong component
		−31.	faint component
4348 A	1906, August 1	+30.	strong component
		−25.	faint component
4353 A	1906, August 6	− 4.	lines single
4467 A	1906, September 30	+ 3.	lines single

The star is an F type, with broad lines. Both spectra are visible. The ratio of their intensities is about two to one, although all lines do not behave alike in this respect. The variable velocity and doubling of spectrum were discovered by Mr. Burns, by whom all of the above measures were made. From his observations of the variation from coincidence of the two spectra it seems probable that the masses of the stars are not very different.

δ *Sagittae* ($\alpha = 19^h\ 42^m.9$; $\delta = +18°\ 17'$)

Plate	Date	Velocity	Measured by
1371 B	1899, August 7	+10. km	Campbell
		+ 8.	Stebbins
1392 B	1899, August 14	+10.	Campbell
1750 D	1900, May 24	+ 9.	Wright
2174 D	1901, June 18	+ 5.	Campbell
		+ 2.	Wright
		+ 5.	Stebbins
2293 A	1901, October 22	+ 3.3	Burns
2407 E	1902, June 8	+ 6.	Stebbins
2932 A	1903, September 9	+ 4.	Moore
4282 E	1906, July 3	− 5.	Burns
		− 3.	Moore

The spectrum is of type M, and is classified by Miss Maury as XVII c. Its variable velocity was suspected by Mr. Campbell from the fourth plate and confirmed by the recent measures.

o^2 *Cygni* ($\alpha = 20^h\ 12^m.3$; $\delta = +47°\ 24'$)

Plate	Date	Velocity	Measured by
3819 D	1905, June 7	−25. km	Moore
3947 B	1905, August 13	−24.	Moore
4326 D	1906, July 22	+ 2.	Burns
4350 D	1906, August 1	+ 5	Burns

The type of spectrum is H. Its binary character was discovered by Mr. Burns from the third plate.

ϵ *Cygni* ($\alpha = 20^h\ 42^m.1$; $\delta = +33°\ 36'$)

Plate	Date	Velocity	Measured by
165 B	1896, September 23	−13.6 km	Campbell
480 A	1897, August 31	−14.	Burns
941 A	1898, September 15	−11.8	Campbell
2190 E	1901, July 3	−12.	Wright
2821 B	1903, June 20	− 9.	Curtis
4263 C	1906, June 27	− 7.	Burns
		− 6.3	Newkirk
4375 B	1906, August 24	− 7.	Burns

This is a K-type star. The variation in velocity was suspected by Mr. Curtis and confirmed by Mr. Burns.

ζ Cygni ($\alpha = 21^h\ 8^m.7$; $\delta = +29°\ 49'$)

Plate	Date	Velocity	Measured by
183 B	1896, October 5	+19.6 km	Campbell
764 A	1898, June 8	+21.	Burns
772 A	1898, June 15	+21.	Campbell
865 B	1898, August 8	+20.	Campbell
2398 D	1902, June 2	+15.	Stebbins
4277 F	1906, July 2	+14.	Burns
		+13.9	Newkirk
4364 D	1906, August 13	+14.	Burns

The type of spectrum is K. The variable radial velocity was shown by the measures of Mr. Stebbins and Mr. Burns.

ι Capricorni ($\alpha = 21^h\ 16^m.7$; $\delta = -17°\ 15'$)

Plate	Date	Velocity	Measured by
1788 D	1900, June 26	+12. km	Wright
1890 B	1900, September 19	+13.	Wright
2923 D	1903, September 7	+ 8.	Moore
4267 D	1906, June 29	+18.	Burns
		+16.	Moore
4383 B	1906, August 26	+14.	Burns
4430 B	1906, September 16	+ 9.	Moore

This star is an H-type. The variable velocity was suspected by Mr. Moore and confirmed by the recent measures.

SU Cygni ($\alpha = 19^h\ 40^m.8$; $\delta = +29°\ 01'$)

This variable, of the *δ Cephei* type, was found to be a spectroscopic binary by Mr. J. D. Maddrill[1] from observations of its radial velocity made during the past summer with the one-prism spectrograph. Its spectrum is of type F–G.

W. W. CAMPBELL
J. H. MOORE

MOUNT HAMILTON
November 12, 1906

A LIST OF SOUTHERN STARS HAVING VARIABLE RADIAL VELOCITIES

From an examination of plates secured by the D. O. Mills Expedition to the Southern Hemisphere, the following stars have been found to have variable radial velocities:

[1] Announced by Mr. Maddrill in *Publ. A. S. P.*, **18**, 252, 1906.

β Reticuli ($\alpha = 3^h\ 42^m.9$; $\delta = -65°\ 7'$)

Date	Velocity	Negative by[2]	Measured by[2]
1903, December 7	+54.5 km	W.	R. H. C.
1904, January 4	+53.8	W.	P.
December 18	+48.2	P.	W.
1905, November 5	+47.4	W.	W.
November 5	+47.1[1]		A.
December 28	+48.1	W.	W.

The spectrum of this star is of type K.

m Velorum ($\alpha = 9^h\ 47^m.9$; $\delta = -46°\ 5'$)

Date	Velocity	Negative by[2]	Measured by[2]
1905, January 10	− 3.6 km	W.	W.
January 28	− 0.9	W.	P.
March 13	+ 8.2	P.	P.
April 3	+12.8	W.	W.
April 3	+10.9[1]		A.
December 6	− 2.6	W.	W.

[1] Independent measure of above plate.

The type is G 5 K.

ν Centauri ($\alpha = 13^h\ 43^m.5$; $\delta = -41°\ 12'$)

Date	Velocity	Negative by[2]	Measured by[2]
1904, April 20	− 1. km	P.	P.
1905, January 25	+ 4.	P.	P.
March 18	+28.	P.	P.
April 3	+ 9.	W.	P.
April 13	+33.	P.	P.
April 27	− 1.	P.	P.

[2] The observers indicated in these columns are Messrs. Palmer, R. H. Curtiss, Albrecht, and Wright.

The type is B 2 A.

Dr. Palmer assigns a period of about thirty-one days to this star.

v^2 Centauri ($\alpha = 13^h\ 55^m.4$; $\delta = -45°\ 7'$)

Date	Velocity	Negative by[2]	Measured by[2]
1904, April 6	+4.3[2] km	P.	W.
April 6	+3.0[1]		P
May 16	+5.4	W. & P.	W.
1905, March 15	−7.8	W.	W.
April 4	−7.8	W.	W.
1906, January 22	+3.1	W.	W.

[1] Footnote page 1.

[2] Poor plate, underexposed.

The type is F 5 G.

The variable velocities of *β Reticuli* and *ν Centauri* were detected by Dr. Palmer from preliminary measurements of the third plates.

MOUNT HAMILTON,
November 14, 1906

W. H. WRIGHT

THE VARIABLE RADIAL VELOCITY OF *ANTARES*

Approximate measures of a number of the earlier Mount Hamilton spectrograms of this star placed its velocity at −6 km per second. The star was on the working list of the D. O. Mills Expedition, at Santiago, and rough measures of a spectrogram secured on March 22, 1905, indicated a velocity of −1 km. A number of other observations were secured and an earlier plate was measured. The following are the observations obtained by the Expedition:

Date	Velocity	Measured by	Notes
1904, June 24	−2.3 km	Palmer	Underexposed
1905, March 22	−1.	Wright	
March 28	−0.9	Wright	
March 29	+1.2	Wright	

These determinations differed by about 6 km from the Mount Hamilton observations referred to above, and afforded a strong indication of variable velocity. At the direction of Dr. Campbell, the star was re-observed at Mount Hamilton, and the old plates were definitively measured. Mr. Burns's results, as given below, fully confirm the variability:

Date	Velocity	Measured by
1897, April 8	−3.9 km	Burns
May 19	−6.2	Burns
July 8	−5.4	Burns
1899, July 18	−1.4	Burns
1902, May 27	−4.6	Burns
1905, May 14	+2.0	Burns
May 23	+0.4	Burns
1906, July 18	−2.4	Wright

Miss Maury finds indications of a secondary or faint superimposed spectrum in the case of *Antares*, but this is referred to as being probably due to the telescopic companion.[1]

MOUNT HAMILTON
September 10, 1906

W. H. WRIGHT

[1] *Annals H. C. O.*, **28**, 100, Remark 155.

THE RADIAL VELOCITY OF *POLARIS*

The following radial velocities of *Polaris* were secured from Mills spectrograms:

Gr. M. T. 1906	Velocity	Measured by
July 8^d 22^h 43^m	−14.2 km	Campbell
9 00 23	−13.9	Campbell
9 16 33	−14.4	Campbell
10 00 01	−17.8	Campbell
10 17 25	−18.9	Campbell
11 17 05	−17.3	Campbell
12 00 11	−16.2	Campbell
19 00 19	−20.8	Campbell

According to these results the velocity-curve for the four-day binary system attained a minimum value of −19.8± km, determined graphically, at the epoch 1906.5. The minimum at 1904.5 was −18.5± km.[1] At 1896.9 it was −20.7 km.

W. W. CAMPBELL

November 23, 1906

NINE STARS HAVING VARIABLE RADIAL VELOCITIES

I. VARIABLE STARS

RZ Cassiopeiae = 77 1906 = *B D.* 69°179

($\alpha = 2^h\ 40^m$; $\delta = +69°\ 13'$; Mag. = 6.5 to 8.0)

The spectrographic observation of this *Algol* variable was begun by Mr. Parkhurst on August 26, 1906, in connection with its photometric investigation by photography. The plate showed that the spectrum was well measurable, so that the star was placed on the programme for future observation. Mr. Parkhurst's second plate, on September 2, was taken at nearly the same phase of the star's variation (about three hours before minimum) and shows very little change in radial velocity. The radial velocity on these plates is roughly −9 km. The third plate, however, secured by Frost and Barrett on September 24 closely at the predicted time of greatest velocity of approach, 7 hours after minimum, yields a radial velocity of −114 km, according to my provisional measures. The fourth spectrogram, taken by Mr. Fox on November 4, eleven hours before minimum, gives a value of approximately −5 km. Unfavorable

[1] Lick Observatory Bulletin, **3**, 86, 1905; *Astrophysical Journal*, **21**, 191, 1905.

weather has so far defeated our attempts to secure a plate at the phase of maximum positive velocity.

After this star had been included in the first draft of this note, *Astronomische Nachrichten* No. 4135 arrived, in which Professor Hartmann reports his recent observations of the star. Our value for maximum approaching velocity is in good agreement with the data of his preliminary note.

The star has the *Orion* type of spectrum, as is commonly found in the case of *Algol* stars, with the helium lines faint. The hydrogen lines are much sharper than usual, and numerous enhanced lines of the metals may be seen, particularly of *Ti* and *Fe*.

X Cygni ($\alpha = 20^h\ 39^m$; $\delta = +35°\ 14'$; Mag. = 6.4 to 7.5)

In 1905 one one-prism plate of this short-period variable star (type of δ *Cephei*) was secured by Mr. Barrett, and in 1906 three by Mr. Parkhurst and one by the writer. I have made approximate measurements of the last four plates and find a range of over 50 km in the radial velocity. The spectrum is of an advanced F type, suitable for fairly accurate measurement, but the spectrocomparator would probably prove particularly advantageous for it. The period of the star's variation of light is given as $16^d\ 9^h$—from minimum to maximum $6^d\ 5^h$, from maximum to minimum $10^d\ 4^h$. A considerable number of plates will therefore be necessary to cover the different phases. The largest positive velocity on these four plates was shown two days after minimum, with a small negative velocity two days after maximum. The velocity is also small half-way between maximum and minimum. Such results are to be expected from analogy with the spectrographic observations of δ *Cephei* and other stars of this class.

II. VISUAL BINARIES

13 Ceti ($\alpha = 0^h\ 30^m$; $\delta = -4°\ 9'$; Mag. = 5.3)

Spectrograms of this star have been secured by Mr. Barrett or myself in the course of our regular programme of observations of visual binaries, for the ultimate determination of their parallaxes. The spectrum is an excellent example of the F type and can be accurately measured. Thus far I have had time to make only approxi-

mate measurements, depending chiefly upon the iron lines λ 4384, 4405, and 4415. The first plate, taken September 29, 1905, is rather too faint for measurement, as was the second, on August 20, 1906. The third, of date October 1, showed about the same velocity, but the fourth spectrogram, taken November 9, indicated to the eye a large change of velocity, which was measured to be over 30 km. Four additional plates have since been secured, Mr. Fox assisting in the exposure of the last three. The dates are November 23, 24 (two-prism plates), and December 1 and 3. A total range of over 50 km is indicated, and the last four plates make it appear probable that the period is about two days. The exposure time is kept as short as possible, to avoid the effect of the second star of the visual pair, which is about one magnitude fainter. The short period of revolution of the visual pair, probably less than twenty-five years, makes this an interesting system, and I hope that we can secure enough data during the present opposition for the definitive determination of the spectrographic orbit.

ω Leonis ($\alpha = 9^h\ 23^m$; $\delta = +9°\ 30'$; Mag. = 5.6)

This star is also on our regular programme of visual binaries, and two plates were taken in 1905, on February 3 and March 3. Approximate measures showed that the velocity changed by over 20 km. The third plate, on March 30, 1906, increased the range by about 5 km. The iron lines above mentioned are very sharp, and they were used for the provisional measurement. Nothing can be said at present as to the period of variation.

An apparent variation in the distinctness of other lines of the spectrum (early solar type) may be due to the effect of the light of the second star of the visual pair, which is called by double-star observers about one magnitude fainter than the principal star. The period of the visual pair seems to be somewhat over a hundred years, from the best recent observations.

85 Pegasi ($\alpha = 23^h\ 57^m$; $\delta = +26°\ 34'$; Mag. = 5.8)

I have been suspicious for the past year as to the constancy of the radial velocity of this star. The spectrum is of the solar type, and the accuracy of the measurements would be proportional to the

dispersion used; of the eleven plates we have so far secured, nine were taken with one prism and two with two prisms. An exposure of from two to three hours is required with our apparatus for a strong one-prism spectrogram. Four hours of exposure are needed with two prisms. The use of three prisms is therefore precluded for our instrument.

The construction of the Bruce spectrograph is so rigid that I am not much concerned as to internal flexures. I have been unable to detect any effect of displacement on trial exposures of the comparison spectrum made first with the telescope on the meridian, and second with the telescope pointing at an hour angle of six hours. But it is certain that with very long exposures the illumination of the collimator lens by the star's light must be progressively changing, due to flexure of the tube of the refractor; since prisms and lenses are not perfectly homogeneous, this must have an unfavorable effect. I should therefore hesitate to determine radial velocities from spectrograms requiring much over four hours of exposure. Where the star's declination permitted, the telescope would in such cases be run under the pier for the latter half of the exposure, so that the hour angle would be divided as nearly equally as possible on the east and west sides of the meridian. But I should never regard it as safe to reverse the telescope and conclude the exposure on the other side of the pier.

On account of the small dispersion and rather long exposures, I therefore give the results of the observations of *85 Pegasi* with some reserve; and most of the measures are to be regarded as provisional. When our spectrocomparator arrives, I expect to go over all the plates, as that instrument doubtless will be of great assistance in measuring such spectra.

The comparatively small range of the variation is no argument against its reality, however, and it is difficult for me to believe that errors of observation can account for the range of 10 km shown, for instance, by the excellent plates of October 31 and December 1, when the conditions of the spectrograph were very similar. The results so far obtained are as follows:

Plate	Date	G. M. T.	Taken by	No. Lines	Velocity	Remarks
IB 580	1905 Aug. 28	21h 2m	B.	..	.....	Comp. lines too faint
604	Oct. 2	16 41	F.	5	—42 km	fair plate
612	Nov. 10	14 8	F.	13	—31	good
IIB 21	Nov. 20	16 41	F. & B.	14	—35	fair
IB 823	1906 Aug. 13	19 45	B.	4	−34	good
830	Aug. 20	18 20	F. & B.	4	(−28)	weak
861	Sept. 21	20 35	F.	5	−39	good
891	Oct. 31	14 37	F.	6	−33	good
913	Nov. 9	15 57	B.	4	(−30)	too weak; exposure 56m
IIB 88	Nov. 23	17 7	F. & B.	14	−38	fair
IB 920	Dec. 1	15 38	Fox	5	−43	good

Like *13 Ceti*, this visual binary system is of particular interest on account of the shortness of its period, which cannot much exceed twenty-five years. In this connection it should be noted that Campbell found *κ Pegasi* and *ε Hydrae*, two visual binaries having the shortest periods after *δ Equulei*, to be spectroscopic binaries.

III. STARS OF *ORION* TYPE

19 τ⁵ Eridani ($\alpha = 3^h\ 29^m$; $\delta = -21°\ 58'$; Mag. = 4.2)

This spectrum is characterized by exceedingly broad and vague lines, which by their recurrent duplicity prove the star to be a spectroscopic binary with components of about equal brightness. It will not be possible to measure the radial velocity accurately. The *Mg* line at λ 4481 is the best in this part of the spectrum. The plates so far obtained are as follows:

Plate	Date	G. M. T.	Taken by	Remarks
IB 638	1905 Dec. 15	14h 45m	F.	λ 4481 single, also *Hγ* and *Hβ*
884	1906 Oct. 19	18 12	F. & B.	λ 4481, *Hγ* & *Hβ* double
902	Nov. 1	17 55	P.	λ 4481 double; *Hγ* faintly so; *Hβ* not visibly separated
922	Dec. 14	16 30	Fox	λ 4481 double, broader comp. displaced toward red
930	Dec. 17	16 19	F.	λ 4481 double, broader component displaced toward violet

Rough measurements of plate 884 give an almost equal displacement of the two components of λ 4481, corresponding to velocities of about −95 km and +110 km (after applying a correction of

+7 km for the Earth's velocity). The broader component was the one displaced toward violet.

Similar measures of No. 922, a weak plate, give values of about −60 and +140 km. On Plate 930 the positions of the components are reversed, whence we may infer that the period is short.

33 τ^8 Eridani ($\alpha = 3^h\ 49^m$; $\delta = -24°\ 55'$; Mag. = 4.7)

Five spectrograms have been obtained of this star, of our regular *Orion*-type programme. The spectrum is an example of the better measurable variety of the type, with the helium lines fairly sharp and λ 4481 especially so. Rough measures show a range of over 25 km in the radial velocity. On two of the plates the helium line at λ 4472 gives evidence of duplicity. Nothing can yet be inferred as to the period from our plates, of which the dates are 1905, December 15, 25; 1906, January 26, October 19, November 1.

20 τ Orionis ($\alpha = 5^h\ 13^m$; $\delta = -6°\ 57'$; Mag. = 3.6)

This spectrum has quite good lines; $H\gamma$ is narrower than usual for the type; λ 4481 is also good, and the helium lines are fairly sharp. The first two plates were measured by both Mr. Adams and myself, and the values given are the means of our determinations. The rest of the plates have been measured by Mr. Naozo Ichinohe, Fellow in Astronomy. The data are not yet adequate for finding the period.

Plate	Date	G. M. T.	Velocity
IB 206	1903 Dec. 1	$17^h\ 51^m$	+ 6km
262	1904 Jan. 23	15 56	+12
414	Nov. 1	22 7	+27
628	1905 Dec. 11	16 58	+34
880	1906 Oct. 12	21 24	+22
886	Oct. 19	20 16	+27
896	Oct. 31	21 32	+19
905	Nov. 1	20 40	+27
910	Nov 4	23 00	+16
914	Nov. 9	20 44	+18

4 ξ^1 Canis Majoris ($\alpha = 6^h\ 28^m$; $\delta = -23°\ 21'$; Mag. = 4.2)

The lines in the spectrum of this star are excellent, and it was accordingly selected for early measurement from the large number of unmeasured spectrograms in our cabinet. The first plate was

first measured by Miss F. A. Graves, formerly computer at this observatory. Her result was +36 km. The measures below are by Mr. Ichinohe.

Plate	Date	G. M. T.	Velocity
IB 508	1905 Feb. 6	$16^h\ 20^m$	+37 km
523	Mar. 3	14 43	+32
632	Dec. 11	20 10	+22
923	1906 Dec. 14	17 31	+23

With the exceptions noted, the spectrograms referred to in this communication were made with the one-prism arrangement of the Bruce spectrograph. The lower dispersion is better suited for most stars of the *Orion* type, and was necessary for securing the spectra of the faint stars of the solar type without unduly prolonged exposure.

As usual, Mr. Sullivan has rendered valuable assistance in guiding.

EDWIN B. FROST

YERKES OBSERVATORY
December 20, 1906

NOTE ON THE INTERPRETATION OF THE SPECTRA OF THE COMPONENTS OF DOUBLE STARS SHOWING CONTRASTED COLORS

In 1897 we sent a short note to the *Astrophysical Journal*[1] on the spectra of the strongly contrasted colored components of some double stars, which the newer form of my reflecting slit had made it possible for us to photograph separately.

Assuming these double stars to have originated by tidal evolution from one original mass, the pairs of stars at their birth would have been in the same evolutionary stage, and composed of the same substances, though not necessarily in the same relative proportions. The spectra of such pairs of stars should then indicate the evolutional stages which the components had severally reached; the successive stages coming in, it may be presumed, at an earlier time in the case of the component which has the smaller mass. We were met at once, as we then pointed out, by the apparent anomaly that it is the brighter, and as was then assumed the more massive star, which

[1] **6**, 322, 1897.

shows a more advanced phase of development, while the relatively faint companion remains still in the earlier white-star stage.

We ventured to say that there is no certain ground for assuming that the brighter star is actually the more massive one. I had already in 1891[1] pointed out that "the brightness of a star depends upon several conditions and must be largely affected by the nature and the condition of the substances by which the light is chiefly emitted, as well as by the absorbent atmosphere through which it has to pass."

We suggested, therefore, that the smaller star, usually bluish in color, though so much less brilliant, might have the greater mass, and for this reason be still at an earlier evolutionary stage.

This view of the relative masses of the components of double stars was further supported by the spectra of other double stars reproduced in our *Atlas of Representative Stellar Spectra* (Plates XI and XII), 1901.

Quite recently our contentions have received remarkable confirmation from the work, on wholly independent lines, of Mr. T. Lewis on the relative masses of the components of eighteen binary stars.[2]

Mr. Lewis' results are summed up as follows: "They [the relative masses] establish the curious persistency of an opposite disparity, among the members of unequal pairs, between light and mass. The apparent satellite is in fact the primary of the system."[3]

UPPER TULSE HILL
December 15, 1906

SIR WILLIAM AND LADY HUGGINS

PRELIMINARY NOTE ON THE SPECTRUM OF *o CETI* (*MIRA*)

The spectrum of this well-known long-period variable has been photographed on four evenings during its present bright maximum.

The dates of the plates are as follows:

	1906	Spectrograph	Region Included
No. 1.....	Dec. 13	Three-prism	λ 4300 to λ 5000
No. 2.....	Dec. 18	Single-prism	*Hδ* to *Hα*
No. 3.....	Dec. 21	Single-prism	*Hδ* to *Hα*
No. 4.....	Dec. 24	Single-prism	*Hδ* to *Hα*

[1] Address Brit. Assoc. 1891, pp. 16, 17.

[2] "Measures of Double Stars," *Mem. R. Astron. Soc.*, **56**, xxi, 1906.

[3] *Ibid.*, p. xx.

I am indebted to Mr. E. C. Slipher, Fellow at this Observatory, for exposing the last plate.

Vanadium, iron, and sodium were used for the comparison spectrum.

No. 1. Only two hydrogen lines, $H\beta$ and $H\gamma$, are comprised in the region covered by this plate. These lines are both strong and bright.

No. 2. The spectrum on this plate extends from below C to and including $H\delta$. The continuous spectrum is, however, somewhat weak from λ 6250 to 5000 and from λ 4300 toward the violet. The plate shows the following bright lines: $H\alpha$, $H\beta$, $H\gamma$, and $H\delta$. Although $H\alpha$ (C) is far from weak it is not nearly so strong as the other hydrogen lines, which appear to increase in strength in the order given.

No. 3. This plate contains a splendid impression of the continuous (absorption) spectrum from λ 4200 to λ 6200. It shows a great many absorption bands which are sharp and intense on the more refrangible edge and gradually fade out toward the red. Of the hydrogen lines, $H\beta$, $H\gamma$, and $H\delta$ are strong and bright, and, although the plate is weak beyond λ 6200, there is a faint impression of bright $H\alpha$.

No. 4. The continuous spectrum, although somewhat lacking in density, extends from λ 4300 to below $H\alpha$. The hydrogen lines $H\alpha$, $H\beta$, $H\gamma$, and $H\delta$ are all bright. $H\alpha$ is very sharp, and has bordering it on the violet a strong and rather broad absorption line. This absorption line is also well shown on plate 2.

A word of caution may not be out of place here regarding the remarks on the continuous spectrum of the different plates; for, as a different kind of photographic plate was used in each case, no conclusions are to be drawn as to changes in the continuous spectrum during the period of these observations.

This is the first time, to my knowledge at least, that bright $H\alpha$ has been observed either visually or photographically in *Mira* or any of the long-period variables of its class. However, I believe that this is not to be interpreted as an unusual behavior of $H\alpha$. It is probable that its faintness relative to the other hydrogen lines has made it difficult to observe visually.

Vanadium absorption lines are very strong in *Mira* as compared with other metallic lines.

LOWELL OBSERVATORY, FLAGSTAFF, ARIZ. V. M. SLIPHER
December 29, 1906

A VERTICAL COELOSTAT TELESCOPE[1]

One of the most difficult problems of the Solar Observatory is that of designing a telescope to meet the rigorous requirements of solar research. The distortion of mirrors, and the local disturbances of the atmosphere, caused by the Sun's heat, are obstacles more serious than any encountered in the case of night observations. The peculiar advantage of the equatorial refractor—viz., that the object glass is not seriously distorted, nor the focus greatly changed, by exposure to sunlight—is offset by the necessity of attaching all spectroscopes and other accessory apparatus to a movable telescope tube. This defect of the equatorial has greatly retarded the progress of solar research, by delaying the application of long-focus grating spectrographs to the study of the solar image.

Many important investigations require the provision of a telescope giving a sharply defined solar image, of large diameter, at a fixed position within a laboratory. The focal length of such a telescope must not change rapidly when the instrument is exposed to the Sun. The image must not rotate, and the laboratory conditions must permit the successful use of the largest and most powerful spectrographs and spectroheliographs.

The Snow telescope meets most of these requirements in a very satisfactory manner. Under suitable atmospheric conditions the large solar image given by it is so sharply defined as to resemble a steel engraving. The five-foot spectroheliograph has permitted excellent photographs of this image to be obtained with the lines of calcium, hydrogen, iron, and other substances. A Littrow spectrograph of eighteen feet focal length has provided the means of photographing the spectra of sun-spots, and the results have proved very useful in the study of the strengthened and weakened lines. The one difficulty with the Snow telescope is the distortion of the image and the change of focus when the mirrors are exposed for some time to the Sun. This is not serious in our present work, since short exposures suffice in photographic observations with the five-foot spectroheliograph and the Littrow spectrograph. But if long exposures were needed, as in the case of a thirty-foot spectroheliograph, the

[1] *Contributions from the Solar Observatory*, No. 14.

change of focus during the exposure would be a serious obstacle. Various ways of overcoming this difficulty have suggested themselves, and one of these will shortly be tried. But since the Snow telescope is fully occupied with its present work, for which it has proved to be well adapted, it has become necessary to devote special attention to the design of a second coelostat telescope. The daily program of observations keeps the Snow telescope so constantly in use that all new work, such as the application of the thirty-foot spectroheliograph, and the study of sun-spot spectra with the remarkable eight-inch grating, recently made and offered for our use by Professor Michelson, must be deferred until the new telescope is completed.

A careful study of the requirements of solar research on Mount Wilson has led me to the following conclusions:

1. A coelostat should be employed, in preference to any form of heliostat or siderostat, since it causes no rotation of the solar image.

2. The coelostat should be mounted at a considerable height above the ground, to reduce the effect of the hot air rising from the Earth.[1]

3. The ground about the instrument should be shaded, for the same reason.

4. The telescope should be best adapted for early morning and late afternoon observations, the former being the more important, because of the better definition.

5. All the mirrors employed should be completely filled with sunlight, to obviate irregular distortion.

6. The mirrors should be extremely thick, to reduce the degree of bending caused by heating.

7. The backs of the mirrors should be silvered, and exposed to sunlight, to compensate bending.

8. The beam of light, after reflection from the second mirror, should be vertical, to reduce the danger of disturbances across the wave-front.[2]

9. The image should be formed by an object-glass instead of a

[1] See report of observations made from a tree, etc., in "A Study of the Conditions for Solar Research at Mount Wilson, California," *Contributions from the Solar Observatory*, No. 1, pp. 23, 25, 26.

[2] The advantages of a vertical beam have been pointed out by Plummer in *Monthly Notices*, **65**, 500, 1905. They have also been mentioned by Frost in a personal letter to me.

concave mirror, in order to bring the focal plane near the ground, to reduce variations of focal length, to shorten the path between coelostat and image, and to facilitate the use of a large spectroheliograph.

10. The walls below the coelostat should be constructed so as to heat as little as possible, when exposed to the Sun. Other devices may also be employed to decrease the evil effects of rising currents of heated air.

11. The spectroscopic laboratory should be below ground, to insure constancy of temperature and great stability of the instruments.

The vertical coelostat telescope shown in outline in the figure, is the outcome of experience with the Snow telescope, and is intended to satisfy the conditions named above.

Two entirely independent galvanized steel towers (about 60 feet high) are required: one (in lieu of a pier) for the support of the coelostat, the other to shield the inner tower from the wind.[1] The outer tower is to be covered with canvas louvres (not shown in the sketch) similar to those used on the Snow telescope house.[2] To prevent vibrations of the outer tower from being transmitted through the ground to the inner tower, the concrete base of one tower will stand on the surface of the ground, while the foundation of the other will extend below the surface. Guy ropes will also be used where necessary. Indeed, the calm which prevails on Mount Wilson during the best observing hours of the dry season has made it seem advisable to try the experiment of using the inner tower alone at first, depending for stability on a large number of steel guy ropes. The inner tower will be used as a skeleton, without covering, so as to expose but little area. If it does not prove to be steady enough, the other tower, with louvres, will be erected later.

The second mirror stands near the middle of the tower. It is to be elliptical in form, with major axis of $22\frac{1}{4}$ inches (56.5 cm) and minor axis of $12\frac{3}{4}$ inches (32.4 cm). Both this mirror, and the coelostat mirror (17 inches = 43.2 cm in diameter), will be 12 inches (30.5 cm

[1] President Woodward assures me, after his experience in observing from the summit of lofty wooden towers, similarly shielded, in the work of the Coast Survey, that no trouble from vibration need be feared.

[2] *Contributions from the Solar Observatory*, No. 4; *Astrophysical Journal*, **23**, 6, 1906.

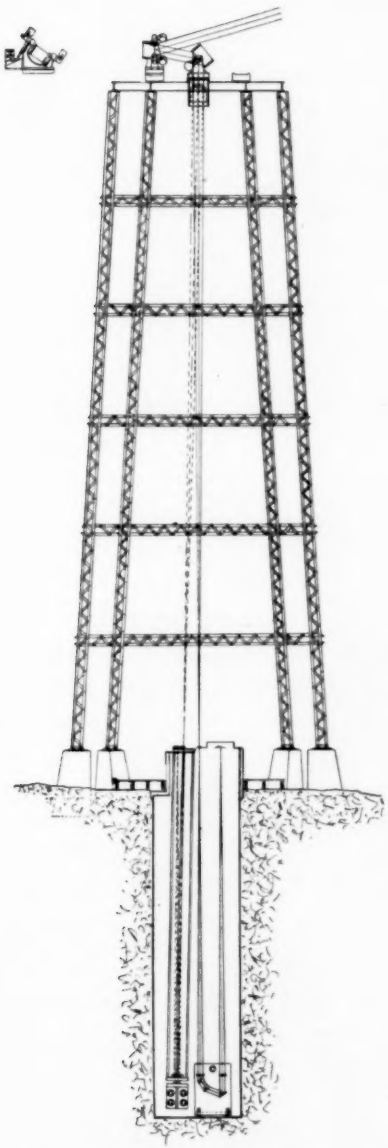


FIG. 1.—Vertical Coelostat Telescope

thick). Experiments made by Professor Ritchey have shown that when a silvered mirror is heated by radiation, the front (warmer) surface becomes convex and the rear surface concave. By placing an electrically heated disk near the rear surface the form can be quickly restored, though the figure, when thus corrected, is not perfect. This experiment, and others involving a test of the curvature of the surfaces, show that the effect of exposing the mirror to sunlight is to produce an actual bending of the mirror. The simple expedient of greatly thickening the disk, so as to increase the resistance to bending, naturally suggested itself to me.

The second mirror is given an elliptical form, so that it may be completely filled with sunlight without undue increase in the size of the coelostat mirror. Its position in this design is such that the polished and silvered back can easily be exposed to the Sun. The angle of incidence is not ordinarily the same as that at the front surface, but the difference is partially offset by the fact that the heating effect of the beam on the face is reduced through the loss incurred by reflection from the coelostat mirror. It is hoped that the great thickness of the mirrors will render more accurate compensation unnecessary.

The coelostat stands on rails, which permit it to be moved north and south. For northern declinations of the Sun it stands north of the second mirror, for southern declinations south, and when the Sun is at the equinox the coelostat is due east or west. The arrangement shown in the figure is that employed with the low morning Sun, for which the telescope will most frequently be used. For the low afternoon Sun the coelostat is transferred, by means of its carriage (which moves easily across east-and-west rails connecting the north-and-south rails at one end) to the rails east of the second mirror. The second mirror is then rotated 180°, and the beam sent vertically downward as before. The back of the coelostat mirror will be heated, if necessary, by sunlight reflected from a large mirror, of ordinary thin plate glass, mounted just behind it. The rails are accurately planed and defined in position, so that the polar axis of the coelostat will always remain in adjustment.

The coelostat will resemble the one used on the Snow telescope,

except for the much greater thickness of the mirror and some improvements in the driving mechanism.

The beam will be reflected vertically downward from the second mirror to a 12-inch (30.5 cm) object-glass, by Brashear, mounted immediately below it. The use of an object-glass, instead of a concave mirror (as in the Snow telescope), is somewhat objectionable, because of its imperfect achromatism. But in practice this is not a serious matter, and the other advantages greatly outweigh this single disadvantage. In the first place, the path of the beam between the second mirror and image, for the same focal length of 60 feet, (18.29 m) is less than half as great as in the Snow telescope, thus reducing the disturbance of the image. Again, the image is formed at a point near the ground, rather than at the top of the tower, where large spectroscopes could not be used to advantage. Finally, the object-glass can be mounted in a carriage, moving on steel balls along rails, thus providing a simple means of producing the motion of the solar image across the collimator slit of the 30-foot (9.14 m) spectroheliograph.

An electric motor, of variable speed, mounted on a pier at the ground level, will drive the photographic plate across the camera slits, and at the same time give synchronous motion to the 12-inch object-glass by means of a vertical shaft passing up through the tower. There will be three collimator slits, so that three photographs of the same part of the Sun may be taken simultaneously with the aid of different lines. The high dispersion of the spectroheliograph should permit some of the narrower dark lines to be used. The collimator and camera lenses (by Brashear) have an aperture of 8 inches (20.3 cm) and a focal length of 30 feet (9.14 m).

The prisms were ordered early in 1905,[1] but have not yet been completed, owing to the difficulty of making suitable glass of the necessary size. For this reason fluid prisms, provided with special means of stirring the liquid contents and of maintaining it at a constant temperature, may be adopted. Slight variations in the position of a spectral line, due to residual fluctuations of temperature, may be compensated by rotating the mirror in the optical train of the spectro-

[1] It was originally intended to use this spectroheliograph with the Snow telescope.

heliograph. For guiding purposes, a line near the one in use would be held in a fixed position, just as in the analogous case of stellar photography.

A small change in the inclination of the mirror at the summit of the tower will cause the solar image to fall on the slit of the Littrow spectrograph, shown at the left of the spectroheliograph. Through the great kindness of Professor Michelson, which I wish especially to acknowledge, this spectrograph will contain an 8-inch (20.3 cm) plane grating, having 500 lines to the millimeter. The aperture and focal length of the objective which serves for both collimator and camera will be 6 inches (15.2 cm) and 30 feet (9.14 m) respectively. The photographic plate will be placed near the slit, as in the case of the Littrow spectrograph used with the Snow telescope. This spectrograph is intended especially for the study of the solar rotation and the photography of the spectra of sun-spots.

GEORGE E. HALE

OCTOBER 1906